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HOW PLANTS ARE TRAINED
TO WORK FOR MAN

BY LUTHER BURBANK Sc.D

GRAFTING AND BUDDING

VOLUME II

EIGHT VOLUMES : ILLUSTRATED
PREFATORY NOTE BY DAVID STARR JORDAN

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NEW YORK

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THE FRAGRANT CALLA

How Fragrance Was Instilled in a Scentless Flower

NOT long ago a young woman visitor who had learned that the function of odor in flowers is to attract bees and other insects made a remark at once naive and wise.

"It seems wonderful," she said, "that bees and other insects generally have the same tastes in color and perfumes that we human beings have. The rose and the apple blossom are sweet to them as well as to us; whereas one might expect that they would care for something quite different, especially when we remember that cultivated people generally like more delicate perfumes than those that please uncultivated people."

This remark, as I said, was at once wise and naive.

It was wise because it showed a tendency to seek causes for things in nature instead of taking them for granted as most people are prone to do.

It was naive because it quite overlooked the true significance of the function of odors in nature.

A moment's further reflection would have shown the young woman that it is not at all a question of the bee liking the things that man likes, but a question of man having learned to like the things that the bee likes.

The fragrance of the flower was not put forth to please or displease man, but to please and attract the insect.

And man learned to like the odors that were constantly presented to him largely because they were constantly presented; just as you may learn to like a food—say, for example, olives—by repeatedly tasting it, though at first you do not care for it.

The exception, of course, is the odor that is associated with unhygienic things, such as decaying vegetable and animal matter. These are attractive to the insects that feed on them because the substances that produce the odors are to these insects wholesome. But they do not attract the bee because they contain nothing on which that insect can feed; and they do not attract us because for us the substances that produce them are pernicious.

But doubtless the carrion beetle finds the odor of decayed meat a much more attractive aroma than the odor of orange blossoms.

And, to make direct application to the case in hand, unquestionably the flies and other insects that are useful to the calla in pollenizing its flowers would be quite unattracted by the sweet and pervasive odor that is given out by the new race of fragrant callas which I am about to describe.

How the Calla Is Fertilized

It was on inhaling the perfume of my fragrant calla that the visitor made the remark I have quoted. And she followed it with this question:

"If the odor of plants is of use to them in attracting bees, why do not all the callas have a perfume like this new one you have developed?"

And here again a moment's reflection would perhaps have supplied the answer. The calla does not need to attract the bee, therefore the production of the chemical substances that give out a sweet perfume would have been a waste of energy for this flower. Perhaps there may have been a time in the past when the calla, like so many other flowers, depended on bees for cross-fertilization, and lured them with its odor; but nowadays the process of cross-fertilization in this plant is effected in a quite different fashion.

If you closely examine the calla you will observe that what you would casually speak of as a single blossom is in reality a case or shield—in point of fact a modified leaf—twisted into a sort of cornucopia and adjusted about a central stalk or "spadix" on which many minute and inconspicuous blossoms are clustered.

The object of this arrangement is doubtless in part to give protection to the flowers, but largely to supply a conspicuous signal to attract night-roving insects, in particular various species of small gnats and flies.

In point of fact the white canopy of the calla affords a very convenient place of refuge for numerous small insects.

Tests have shown that the air inside the calla "blossom," particularly toward its base, where the insects congregate, is perceptibly warmer than the outside air.

It has been proved by recent experiments that the chemical processes associated with plant growth generate heat. Germinating seeds, for example, give out a measurable quantity of heat. So it is not strange, perhaps, that the partially confined air at the base of the tubular calla flower case is at all times a little warmer than the surrounding atmosphere.

In any event the insects find this a snug corner, the attractiveness of which is further enhanced by the presence of a certain amount of edible pollen. In short, for such insect tribes as like the particular fare which the calla offers, its beautiful white tube constitutes a highly attractive lodging place and lunchroom.

Meantime, while the insects are lodging at the base of the stalk on which the true flowers grow, these flowers shed their pollen and let it settle on the backs of the visitors.

And when, in due course, the insects resume their voyaging, they carry the pollen with them and in time transport it to other calla blossoms; for when they enter the new flower they are likely to find the stalk at its center a convenient alighting place, and crawling down this are sure to leave some of the pollen in contact with receptive pistils.

That the pistils shall be those of a different plant from the one that supplied the pollen is insured by nature's familiar device of having the stamens and pistils of the same flower ripen at different times.

A Gift of Nature

All this sufficiently explains the utility of the large white modified leaf or spathe which we

THE SPADIX OF ONE OF THE CALLA LILIES

From this direct-color photograph it will be seen that the central stalk within the lily, called the spadix, is in fact a composite flower itself, on which many minute and inconspicuous blossoms are clustered. Both these staminate blossoms and pollen grains at the top, and the pistillate ones lower down, may be clearly seen.

commonly speak of as the calla's flower, and also the normal habit of this flower in producing only the musty odor which is rather disagreeable to us, but which is obviously attractive to the particular insects which the calla needs as coadjutors.

But it does not explain how it chanced that among a large quantity of seedlings of a tribe of calla, known as the "Little Gem," I one day found a single specimen that not only lacked the disagreeable smell of the others, but had a mild yet unmistakable aroma that was distinctly pleasing.

Explanations aside, such a specimen did appear among my callas, and it was by raising seedlings from this anomalous specimen and carefully selecting the best specimens for successive generations that I developed the perfumed calla.

The first plants that grew in the first generation from seeds of the first fragrant calla showed no improvement over their parent in point of fragrance. But in the second generation, as so often happens, there was a marked tendency to variation, and from among the numerous seedlings of this generation I was able to select one that had a fully developed and really delightful perfume.

By propagating this specimen as usual, by division, fragrant callas precisely like the mother plant were soon developed in quantity.

Other races showing the quality of scent-production in varying measure were produced from the seed, but no one of the seedling varieties ever equaled the selected plant, and the finest fragrant callas in existence to-day are all the descendants, through the process of division, of the original second generation seedling.

This new race of callas was named the "Fragrance."

Fortunately it chanced to combine with the habit of perfume production the habit of abundant and constant blooming. Indeed, in this regard it probably excels all other varieties of calla.

The New Calla a "Sport"

It thus appears that the perfumed calla was developed through selection, and in the short period of two generations, from a perfumed individual that appeared "spontaneously" among some thousands of odorless seedlings.

Using a term that is peculiarly popular in recent years, we might say that so marked a variation from the normal or usual form of calla constituted a "mutation."

In the size and color and general appearance of its flower, as well as of its entire structure, the new calla precisely resembles its fellows. Yet we are surely justified in speaking of so very marked an anomaly as the production of a strong perfume as constituting an important departure from the normal.

No one knows precisely what the chemical changes are that produce the perfume of a flower, or through precisely what transmutation of forces one flower is made to produce an odor quite different from the odor of other flowers.

But for that matter no one knows just what are the conditions that induce the stimulus that we interpret as an odor of any kind. The sense of smell seems the most mysterious of our senses.

But whatever these inherent conditions may be, they constitute changes in the intimate structure of the plant itself that must be admitted to be important in character, inasmuch as they have to do with the well-being of the plant, and may even determine—through their appeal or lack of appeal to insects—the perpetuation or the elimination of a species.

In the case of the scented calla it was perfume that differentiated a particular individual from thousands of other individuals growing in the same plot.

On this basis alone I selected this particular flower, put it in a plot by itself, gave it every encouragement, and determined that its progeny should live and perpetuate the particular strain it represented; whereas but for this single feature of variation, that individual plant would in all probability have been destroyed along with hundreds of others.

The development of the fragrant calla, then, through artificial selection based on the recognition of the value of fragrance as an addition to the attractiveness of this flower, represents in a small way and in epitome the history of the development of numberless races in nature through the operation of natural selection.

In this particular case, natural selection probably would not have resulted in the production of a race of fragrant callas, because, as already pointed out, fragrance of this character has no value for this particular flower. It might even chance that the fragrance which to our senses is exquisite would prove unattractive or even repellent to the flies that normally frequent the spathe of the calla and aid it in perpetuating its species.

In that case natural selection would certainly insure the early destruction of the race of fragrant callas. It may well have been through such

discriminative selection on the part of insects that the calla lost its scent in the past ages. For of course natural selection can operate even more effectively in weeding out organisms that have undesirable traits as in perpetuating organisms that show favorable variations.

One process is necessarily complementary to the other; they are two sides of the same shield.

In another connection we shall have occasion to deal more at length with the processes of natural selection; and we shall see numberless examples before we are through of the way in which artificial selection is instrumental in developing new races of plants.

Foundations of Natural Selection

But for the moment I will consider a little more at length the question of the origin of the variation which resulted in giving this particular calla a perfume that was not normal to its race. In so doing, we shall gain a clue to the genesis of other types of variation or mutation through which various and sundry new races of cultivated plants have originated, and through which also, we have every reason to believe, numberless species of animals and plants in a state of nature have been evolved.

HYBRID CALLAS

A glance at a few of the curious combinations and variations which appear after crossing the various species. Some of the new Callas are of gigantic size, whereas others bear flowers only an inch and a half across.

The presentation of this subject puts us in touch with one of the newest and doubtless one of the most important aspects of the problem of evolution.

Since Darwin we have fully understood that all evolution of organic forms must have its origin in variations. No two individuals even of the same species are precisely alike, and it is not at all unusual to find individuals of a species showing very considerable differences, even as regards the essentials of size and form and function. Indeed, a certain range of such variations is considered to be absolutely normal.

One would never state, for example, that any particular bird has a wing or beak or tail of precisely a given length; instead of this the ornithologist records the *average* or mean length, or the limits of variation shown by different specimens.

And it is universally recognized, since Darwin gave us the clue, that the building up of new species must be brought about through the selection of favorable variations. A bird with an extra long wing, for example, might be able to fly a little faster and secure its insect prey with greater facility than its fellows; and this slight advantage might be instrumental in saving the life of such a bird, and thus enable it to transmit its peculiarity

to offspring that would constitute a long-winged, swift-flying race.

Take the following incident as a tangible illustration.

In the summer of 1904 it chanced that there was a severe drought in New England and there were entire regions in which the insects upon which the common house martin feeds failed to be hatched at the usual time. The result was that there was dearth of food for the martins, and a very large proportion of these birds died of starvation.

In some cases forty or fifty birds would be found starved to death in a single bird house.

There are entire regions in New England today where the martin is a rare or unknown bird, although prior to 1904 it was abundant.

Now, we may reasonably assume that any individual martins that escaped were those that had either greater powers of flight or a stronger inherent tendency to make wide flights in search of food than their fellows. The few individuals thus saved furnish us a concrete example of the survival of the fittest through natural selection. And this illustration is cited at length because it makes tangible the fact, to which I shall have occasion to revert time and again, that the processes of nature through which species have been

developed in the past are still in operation everywhere about us. Many people are disposed to think of natural selection as a principle referring to past times and to the development of organisms long since perfected.

In point of fact past times are like present times in the operation of their laws. The reactions between organism and environment are now what they always were. No race is perfected, no organism freed from the struggle for existence; although, of course, under the conditions of civilization the operation of "natural selection" may be modified through man's influence, and the conditions of life for a given organism radically changed by artificial selection.

Evolution Through Mutation

But let us not forget our theme. With the case of the fragrant calla to furnish our text, I was about to speak of those variations from the normal on the part of any given organism which lie outside the ordinary range of variation and which therefore constitute so definite and pronounced a departure that they have long been spoken of as "sports."

To these some of the present-day evolutionists, following Professor Hugo de Vries, give the name of "mutations."

It has already been said that the appearance of a fragrant calla constitutes such a change. But of course the anomalies that are usually listed as mutations are often of an even more noticeable character. A classical illustration was given by Darwin himself in the case of the Ancon ram, which was born with legs only half the normal length, and from the progeny of which was developed a short-legged race of sheep.

But the word mutation had not come into vogue in Darwin's time, and the idea of evolution through such marked departures from the normal was subordinated in Darwin's interpretation of the origin of species, or at least in that of his immediate followers, to the idea of advance through the preservation of slight variations.

So when, just at the close of the nineteenth century, Professor Hugo de Vries came forward with his "mutation theory," it had all the force of a new doctrine, and was even thought by some enthusiasts—though not by its originator—to be in conflict with the chief Darwinian doctrines.

The observations that led Professor de Vries to the development of this theory were made on a familiar American plant that had found its way to Europe and was growing in profusion by the roadside near Amsterdam. The plant is known as the evening primrose.

Professor de Vries noted a hitherto undescribed variety of this plant in a field near Amsterdam. He took specimens of the plant to his experimental gardens and carefully watched the development of successive generations of seedlings.

To his astonishment he produced in the course of a few generations more than a dozen divergent types of evening primrose, all descended from the original plant, each of which bred true to the new form suddenly assumed. Professor de Vries spoke of these sudden and wide variations from type on the part of his evening primrose as constituting "mutations."

He conceived the idea that similar mutations or sudden wide variations had probably constituted the material on which natural selection had worked in the past. Such mutations being observed to occur in the case of the evening primrose, it is not unnatural to argue that similar mutations might occur in the case of other organisms; and it requires no argument to show that such wide variations offer better material for the operation of the laws of natural selection than could be offered by the minute and inconspicuous variations that had hitherto been supposed to mostly constitute the basis of evolutionary changes.

There were many reasons why the mutation theory appealed to contemporary biologists, thus accounting for its very cordial reception.

For example, there are numberless instances in nature where the development of a useful organ is exceedingly hard to explain on the basis of natural selection, because the organ in its incipient stages could have no utility. Similarly a modification in the location of an organ—say the shift in the flatfish's eye until both eyes are on one side—is difficult to explain as a process taking place by infinitesimal stages, on the basis of natural selection.

A slight shift in position of the eye of the flatfish would have no utility whatever. It is only when the shift has become sufficient to bring the eye on the upper side of the fish that the creature would have any advantage over other flatfish whose eye is on the under side.

If we imagine a mutation in which a fish appears with an eye distorted in location sufficiently to be usable while its owner lies flat on its side in the mud, we can readily understand how such a mutation might be favorable to the individual and thus might furnish material for the development through natural selection of a race of flatfish having both eyes on one side.

We have every reason to believe that the races of flatfish now existing have recently—in a geological sense—developed their observed condition of having the eyes thus located; indeed, proof of this that amounts to demonstration is furnished by the fact that the young flatfish even to this day is born with its eyes located like those of other fishes, the migration of the eye, so to speak, taking place as the individual develops the racial habit of lying on its side.

But as I said, it is unquestionably difficult to conceive how the useful distortion came about unless it began suddenly as a "sport" or mutation. This is one instance among many.

And so Professor de Vries's observation, which proved that mutations do sometimes seem to occur "spontaneously" in nature, was seized on as affording a solution of one of the puzzles of evolution, and the mutation theory was pretty generally regarded as a valuable supplement to the Darwinian theory of evolution.

It should be clearly understood, however, that neither Professor de Vries himself nor anyone else speaking with authority, has thought of the mutation theory as in any sense contradicting the Darwinian theory of natural selection. On the contrary, it is to be regarded as supplementing and supporting that theory. If creatures are

subject to large variations in a single generation, such variations afford peculiarly good material for the operation of natural selection. Moreover, evolution by mutation would presumably be much more rapid than evolution that depended for its leverage upon minute variations.

What Causes Mutation?

Incidentally the idea of relatively rapid evolution, thus given plausibility, answered the objection of certain geologists who had questioned whether the earth had been habitable long enough to permit the evolution of the existing forms of life through the cumulative effect of slight variations.

The mutation theory is thus in many ways acceptable. But to give the theory finality it is obviously necessary to proceed one step farther and ask this question: What causes mutation? And it is equally obvious that the question must be hard to answer.

Professor de Vries, to be sure, made the assumption that the changes in his evening primrose were probably due to altered conditions of nutrition incident to the growth of the plant in a new soil. He further developed a thesis that probably all species are subject to mutation "periods," which recur at more or less regular

periods of their life history, and which thus insure a degree of variation that will make racial evolution possible.

The authority of de Vries sufficed to give wide vogue to his theory; yet it must be admitted that the explanation offered lacks tangibility and at best amounts to little more than begging the question.

To say that altered nutrition produces variation in a plant is in effect to state the fundamental truth that *all plants are more or less responsive to their environment.*

But there is nothing specific in the case of the primrose that explains in any precise way the relation of the change to the particular differences, let us say, between the soil of the original home of the primrose and the soil of Holland. Moreover in numberless other instances plants have been transplanted from one region to another without showing any such pronounced tendency to develop new races.

It was recognition of the difficulties thus presented, undoubtedly, that led Professor de Vries to devise the rather visionary hypothesis of *periods* of mutation with which his theory was cumbered.

But it is a well-recognized law of logic that one should never seek remote and obscure expla-

STRAWBERRIES SHOWING VARIATION

This picture illustrates the variations of fruits that may be expected even if all were grown on vines from the same berry. By selection, each type of berry here shown might have its peculiarities greatly accentuated. Such variation forms the basis of experiments in selective breeding. Only forms and colors can be depicted here. The qualities of firmness, tenderness, sweetness, acidity, aroma, and flavor, as well as vigor and productiveness, must always be taken into account. Also notice the various forms of the calyx.

nations of observed phenomena unless all explanations of a more tangible character have been proved untenable. And it has seemed to me from the outset that in the case of the evening primrose a very much more plausible explanation is at hand than the one devised by the originator of the mutation theory.

In my own opinion, sports or "mutations" are to be explained as a cumulative effect where tension in a certain direction finally results in a more or less rapid change in one or more individuals and may be compared to the breaking of a string by centrifugal force when a weight is more and more rapidly whirled in a circle until the tension is too strong and the weight takes a new course. I am also thoroughly convinced that these more or less numerous abrupt changes are a condition, not a "period" in plant life.

In a word, the varied tribes of evening primrose which Professor de Vries developed in his gardens at Amsterdam were overwhelmingly suggestive of various and sundry new forms of hybrid plants that I myself have developed year after year in my experimental farms at Santa Rosa.

The Primus blackberry, the Phenomenal berry and the sunberry, are, if you wish to so consider them, instances of pronounced mutation, inas-

much as they are fixed forms of plants that vary very widely from the parent forms.

In a single row I have seedling walnut trees two inches high that are of the same age with others six feet in height, both grown from seeds of the same tree, and under exactly the same conditions and this difference continues through the life of the trees. The Shasta daisy and the white blackberry are mutants in the same sense. And as the reader will discover in due course, the list of such anomalies might be extended to tiresome lengths.

In a word, it is perhaps not too much to say that my entire work has consisted in dealing with mutations in plant life. My chief work might be held, and I believe justly held, to be an exposition of the truth of the theory of mutation in so far as it applies to the explanation of the origin of species.

Over and over again, many thousand times in the aggregate, I have selected mutants among my plants and have developed from them new fixed races. But in the vast majority of cases I knew precisely how and why these mutants originated.

They were hybrids; and they were mutants *because* they were hybrids.

And so from the outset I have believed that Professor de Vries's celebrated evening prim-

roses had the same origin. It is true that the parent form was not known to be hybridized, and that there was no known form of evening primrose at hand through which hybridization could have taken place.

But the precise origin of the original plants found near Amsterdam is entirely unknown; and the curious conformity of their offspring, under Professor de Vries's observation, to the habitual variation of hybrid races in the second and subsequent generations is so pronounced that it cannot well escape the observation of anyone who has had large experience with such races.

This fact was at first overlooked by most biologists, largely because they lacked such experience. But now there is a growing tendency to take this view of the case.

Attempts have even been made in very recent years to produce a similar series of mutational forms of evening primrose by direct hybridization of existing forms. And while the results have not been absolutely definitive, they are unquestionably suggestive; and there is without doubt a growing appreciation of the fact that plants may be made to take on the notable changes which are described as mutations by the hybridizing of allied races; and that this explanation of the

origin of mutation has full validity, whether or not it be accepted as the sole explanation.

We shall see the truth of this contention illustrated in scores of cases in the course of these studies.

The Final Interpretation

Meantime for the purposes of present illustration it is necessary to revert to the case of our fragrant calla.

After what has just been said it will be obvious that I would explain this mutation as a reversion due to cross-fertilization.

In other words, some remote ancestors of the calla may have been fragrant, and a chance mingling of ancestral germ plasms in the course of the production of thousands of seedlings of the calla, may have led to such a union of submerged hereditary factors as enabled this latent propensity to make itself manifest.

According to this view, the case is comparable to that illustrated by an experiment in which Professors Bateson and Punnett hybridized two white-flowered peas of different strains and produced offspring bearing flowers colored blue and pink and purple.

The white parent forms were so nearly identical as to be entirely indistinguishable except that

a magnifying-glass showed the pollen grains of one form to be round and the pollen grains of the other form to be oval. This insignificant difference, however, is full proof that the plants belong to different strains.

The union of the divergent strains seemingly brought together pairs of hereditary color-factors —if we hold to the Mendelian explanation—that had been separated and hence had gone unmated for an indefinite number of generations.

In the same way, we may suppose, I had brought together, through a happy chance, in the course of these breeding experiments with the calla, two strains that bore complementary odor-factors, the union of which released and made tangible the latent quality of perfume-bearing, which, in all probability, no calla of either strain had outwardly manifested for hundreds or perhaps for thousands of years.

No race is perfected—no living thing is freed from the struggle for existence.

THE STONELESS PLUM

An Experiment in Teaching a Plant Economy

I WAS exhibiting some examples of the remnants of stones in various specimens of my new plums to a visitor one day, indicating a stone that was like the crescent of the new moon in shape.

"This," I said, "is the plum as it was when the stone was only partially taken out of it. And this"—indicating another one with only a fragment of stone not as large as a grain of wheat—"is the same plum four or five generations later."

The visitor laughed. "That," said he, "reminds me of the museum that showed a skull labeled 'The skull of William Shakespeare,' and another labeled 'The skull of William Shakespeare when he was a boy.' There is this difference, however, that Shakespeare's head, according to the museum record, got larger as he advanced in age, whereas your plum stone became smaller." And then, becoming quite serious, my visitor inspected

a series of fragmentary plum stones that had been placed before him, and added:

"To make a stone grow smaller was certainly a notable feat. How did you manage it?"

This is a question that has been asked more often, in connection with the stoneless plum, than in the case of almost any other of my plant productions. For a plum which looks on the outside precisely like any other, but which is found to be stoneless, never fails to excite surprise.

Even visitors who know what to expect, when asked to bite through one of these specimens, can seldom refrain from exclamations of wonder when the teeth go right through the fruit as readily as they would through a strawberry.

Many persons are not greatly interested in the daisy that combines four specific strains, because they know nothing of the difficulty of making such a union, and are quite unmoved by the spectacle of a white blackberry or a fragrant calla, because they have seen white fruits before, and because fragrant flowers are rather the rule than the exception. But no one ever saw an edible stone fruit without a stone until one was produced here on my farm.

So "How did you do it?" is the universal question of laymen and scientific botanists alike on seeing this really remarkable fruit.

And when an attempt to answer the question is made, the story seems absurdly short and simple; yet to my mind it recalls reminiscences of what was perhaps the most strenuous series of experimental efforts that I ever undertook—a quest that occupied a considerable share of my time for a period of fifteen years, and which even now is not altogether completed.

As you follow the outline of this story, please recall that while it takes but a phrase to tell of the pollenizing of two plum flowers and the production of one anomaly in the first generation and of some other anomaly in the second, in reality a period of five or six years has elapsed between the pollenizing experiment and the observation of the second generation results.

When this is borne in mind and it is further recalled that breeding through many generations is necessary to secure the results desired, it will be clear that the production of a stoneless plum was an achievement that required its full share of patient waiting.

The Raw Materials

At an early stage of my almost endless series of experiments in the hybridizing of plums, I chanced to hear of a so-called seedless plum that was said to grow in France, where it had been

A TYPICAL STONELESS PLUM

People are generally amazed to find it possible to cut directly through a plum that exteriorly looks no different from ordinary plums. (Note the plum at the right, offering no obstacle to the knife blade.) Some visitors are skeptical and cut cautiously into the plum expecting to encounter a stone, and are surprised to find their suspicions unfounded.

known for a long time as a curiosity. About 1890 I sent to the Transom Frères Nurseries in France and secured grafts of this plum, which was known merely as the *Sans Noyau*.

These were grafted on one of my plum trees, and in due course produced a crop of fruit, which, as expected, proved to be a blue-black, cranberry-sized fruit, extremely sour, soft, and unfit for eating either raw or cooked. The original shrub, as I have been informed, and as it grew here, is a rambling, thorny bush rather than a tree, utterly worthless for any purpose except the one for which I desired it. The fruit, besides being flavorless and unpalatable, was scanty in yield.

Moreover the fruit was by no means stoneless, notwithstanding its French name. It was only partially stoneless, as most specimens produced fair-sized kernels in the fruit, and every kernel had a thick rim of stone around one side partially half covering the kernel. While it therefore lacked much of exhibiting the condition of stonelessness that I had hoped to see, it did nevertheless show a tendency to abandon the stony covering that has always characterized all the fruits of the plum family.

From the outset I was convinced that by proper hybridizing and selective breeding it could be made valuable.

The second season the blossoms of the freak plum were fertilized with the pollen of the French prune and with that of numerous other plums and prunes.

The seedlings from these crosses were grafted to insure their earlier bearing. In the first generation I obtained some plums fully twice as large as their seed parent. Most of these had stones, however, and were soft, sour fruits. A very few of them were partially stoneless, and from these the work was continued.

Getting Results

The next generation gave some general improvement in the growth of the tree and the size and quality of the fruit. All the seedlings of the cross from the *Sans Noyau* were grafted on older trees where they soon bore fruit, even though many of them showed the thorny, dwarfed, ill-shaped type of tree of the uncultivated ancestor.

After still further selection there was a very marked tendency to improvement.

In a large lot of seedlings, in 1904, I obtained two that seemed to me of favorable appearance—for much can be known from the quality of leaf and stem long before the time of fruiting.

And when, two years later, the grafts thus selected bore fruit, it was delightful to find my

predictions verified; the fruit was almost absolutely stoneless, only the faintest splinter of stone occasionally appearing. And combined with this stoneless condition there were qualities of size and flavor that made the fruit practically equal to the French prune. Moreover, as is often the case with hybrids, one strain of which is wild stock, the new plum proved to be a very good bearer.

So my thought of an ideal plum having no stone about its seed was almost achieved.

I say *almost* achieved, because there still remained, in the case of the plums of best quality, a fragment of shell which varied from an insignificant crescent about one side of the kernel to an almost complete obliteration. There were some individual plants among the numberless seedlings that bore fruit in which the stone was absolutely eliminated, and in some cases the seed also.

But it proved extremely difficult to combine this quality of entire stonelessness with the desirable qualities of size and flavor, lacking which the fruit could have no practical value.

Further hybridizing experiments, aimed at the production of an absolutely stoneless plum of fine flavor, are still under way; but in the mean-

time there are several varieties actually in hand that are of the most admirable quality and yet wholly stoneless. In the ordinary French prune, from three to six per cent of the entire fruit is stone; while in my stoneless prune called the "Conquest" the fragment of stone does not represent more than a thousandth part of the bulk or weight of the fruit.

And among the nine or ten hundred varieties of stoneless plums now growing in my orchard, there are sure to be some that will show still further improvement.

Why the Task Was Difficult

The task of producing a stoneless plum had proved very difficult chiefly because it had all along been necessary to bear in mind a number of quite different objective points.

It was not sufficient to produce a stoneless plum. From the practical standpoint there would be no object in that unless the fruit about the stoneless kernel was of good size and of palatable quality. And, unfortunately, there appeared to be no tendency to correlate stonelessness with good quality of fruit.

In point of fact the tendency was quite the other way; and, indeed, this was to be expected in view of the fact that the original partially

stoneless plum was a small acid fruit growing on a wild bush.

The problem was to combine two lines of ancestry that were in many respects directly in conflict. It would have been impossible to do this had it not proved that stonelessness and good quality of fruit, although not originally combined, have the attributes of what may be called unit characters, and hence can be assembled in a single fruit in the later generations of a hybrid progeny.

The Origin of the Stone Fruits

A very natural question arises as to what had originally caused the little French "bullace"—as the *Sans Noyau* is sometimes called—to develop the extraordinary tendency to give up the stony seed covering which no other member of the family had ever been known to renounce.

The question is doubly significant when we recall that some sort of shell or stony covering is almost absolutely essential to the preservation of the seeds of plants in general. The shell is often very thin, as with the seeds of most garden plants. It may be reduced to a mere filament of cellulose, as in the case of a grain of wheat. With pulpy fruits it is usually a very significant covering, of which the seeds of the apple and orange afford typical examples. And with the great

DOUBLE SEEDS SOMETIMES TAKE THE PLACE OF A STONE

In some cases the cavity left in the plum by the removal of the stone is filled by the development of a double seed. We have seen in other illustrations that the hereditary forces seem to be puzzled, if this expression be allowed, in determining how to deal with the altered conditions of the internal structure of a fruit that lacks the supporting stone at its center. One solution of the difficulty is shown in this picture.

tribe of fruits represented by the plums, cherries, peaches, apricots, and almonds, this shell has been developed until it is veritably stonelike in texture.

It is almost self-evident why this extraordinary development of the protective seed covering was necessary in the case of this particular tribe of plants.

It is altogether probable that the original progenitor of all the family of stone fruits grew in central Asia. I have received from that region a shrub that may perhaps be regarded as the prototype of the entire race of the stone fruits—not perhaps the direct progenitor, but an early offshoot from the ancestral stock which has remained in the original environment and has not, perhaps, very markedly changed from the original state during the hundreds of generations in which the other branches of the family were spreading southward and westward across Asia and Europe.

If we could know just what the enemies of the primitive Asiatic stock of the stone fruits were like, we could perhaps surmise the reason for the development of the unusual seed cover.

Perhaps the stone was necessary to protect the kernel from the teeth of monkeys or primitive

men; perhaps it was more particularly needed as a protection against climatic conditions, to insure preservation during semi-Arctic winters; or to keep vitality in the kernel during protracted periods of drought, since, unlike most other fruits, the seeds will rarely germinate if fully dried.

As to all this we can only surmise. But we may have full assurance that the thick, stonelike seed cover served a useful purpose, else it would never have been developed and so persistently preserved in all the divergent races of stone fruits that were evolved under the new conditions of southwestern Asia and southern Europe to which these fruits found their way.

The roving tribes of Arabia developed a tender modified form of the fruit adapted for preservation by drying, and now termed the apricot. Other people consciously or unconsciously selected and developed the almond; and yet others the juicy and luscious peach; while the plum ran wild and put forth a galaxy of hardy offspring that made their way to the north of Europe and also, along some now obliterated channels, to the Western Hemisphere.

But each and all of these descendants maintained, and some of them like the peach intensified and elaborated, the unique characteristic of a

hornlike or stonelike protective covering for the seed.

And so, it becomes matter for wonderment that with all these uncounted generations of heredity clamoring for fruit with a stony covering there should have developed in France a member of the tribe, even though it be an inconspicuous outcast, that rebelled against the family tradition and dared to produce a seed that lacked a part of the habitual covering.

How the Freak Originated

As to just how this break with tradition came about, we can perhaps make a better guess than we can as to the precise origin of the tradition.

It seems likely that the little bullace lost the power to produce a protective stony covering for its seed through the impoverished condition due to some defect in the condition of the soil in which it chanced to grow. Unquestionably the production of the stone makes a strong draft upon the resources of the tree. Obviously the material to supply this dense horny structure must come from the soil, and in case the exact chemicals needed are supplied in scant quantity, the shrub might be forced to economize in producing a shell for its fruit kernel, just as a hen is forced to

economize in the shell covering of her egg in case lime is lacking in her food.

The same sort of economy is practiced when the human child finds inadequate nourishment. In such case the bones may be not only small but defective in mineral substance, a well-recognized type of abnormality resulting with which medical men are familiar.

So it seems plausible that a paucity of proper food materials was the explanation of the origin of the original *Sans Noyau*.

It is in keeping with this explanation that the *Sans Noyau* is, as we have seen, a small scraggly shrub, a mere dwarf as compared with the average stature of trees of its family; and that its fruit is reduced to the proportions of a small berry, and is utterly lacking in those qualities of sweetness and flavor that are the almost universal characteristic of other stone fruits.

In a word, then, it is highly probable that the plum that supplied the character of stonelessness, upon which my experimental endeavors in the production of a marketable stoneless plum was founded, was a pathological product.

I may add that many other "sports" or mutations in the vegetable world that have furnished a basis for the evolution of new races or species may very probably have had the same origin.

Uphill Work

This explanation of the origin of the *Sans Noyau* makes it easier to understand the difficulties that attended the progress of this experiment.

Had the little plum been absolutely stoneless —so that no factor whatever bespeaking a stony fruit remained as part of its heritage—there would probably have been no very great difficulty in producing through hybridization a stoneless fruit of good quality in the second or third generation.

All experiments seem to show that the stone condition is, as might be expected, prepotent, or, in the Mendelian phrase, dominant.

So in crossing an ordinary plum with a stoneless one, it was to be expected that the offspring of the first generation would bear stone fruit. But the latent or recessive trait of stonelessness may be expected to reappear in a certain proportion of the offspring of the second generation; and the stoneless fruit thus produced may in some cases be expected to breed true.

Such is what might be expected provided one were dealing with an absolutely stoneless plum as one of the progenitors.

But unfortunately we are not dealing with an absolutely stoneless plum, but only with one in which the tendency to produce a stone has been minimized *or* partially suppressed. And so our relatively stoneless plum of the second generation still retains traces of the hereditary propensity to produce the stony covering; and, as we have seen, this propensity manifests itself in the fragmentary stone, sometimes reduced to a mere speck in size, that many of my stoneless plums exhibit.

Nevertheless there remains not a doubt that from subsequent generations, from the stock in hand, an absolutely stoneless plum that retains all the valued qualities of the fruit and in all sizes, colors, and flavors desired will be produced.

That it has been possible to eliminate the stone altogether, advancing thus markedly in this regard upon the original partially stoneless form with which the experiment began, suggests the truth of a view now held by some prominent biologists, notably by Professor William E. Castle of Harvard, that a unit character may be modified in successive generations—not merely blended or made into a mosaic with other characters, but actually modified as to its potentialities.

Professor Castle instances in support of this view the case of guinea pigs bred by him that developed a full-sized fourth toe on the hind foot from a rudimentary stump of a toe.

The experiments just cited illustrate the opposite condition of causing a rudimentary organ—in this case a plum stone—to be altogether eliminated.

It should not be overlooked that both experiments are perhaps capable of interpretation in other terms. In each case what actually happens may perhaps be better explained as reversion to a very remote ancestor. Doubtless there were among the ancestors of the guinea pig races with four toes; and doubtless if we go far enough back we should find ancestors of the plum that produced a seed having no stony covering. And we are perhaps not far wrong in assuming that it was the long-subordinated influence of this vastly remote ancestor that, in the case of my plums, sided with me, so to speak, against the forces of the more recent heredity, and made barely possible the ultimate success of my hybridizing experiments.

The Value of the New Product

We are so accustomed to putting up with the annoyance of the stone in the fruit that we for

the most part never give it a thought. But a moment's reflection makes it clear that the plum stone serves man no useful purpose, while the inconvenience it gives us is obvious.

It requires no argument to show that a solid fruit without a stone would be far more acceptable.

But this is not the only reason, although perhaps a sufficient one, for the development of the stoneless fruit. The other reason looks to economy of production and saving of material from the standpoint of the tree itself. It has been estimated that a tree requires several times as much solid material and the expenditure of far more energy to produce the stony covering of the fruit seed than to grow the flesh of the fruit itself.

So it might well be expected that other things being equal, a tree bearing stoneless fruit would prove at least twice as productive as one bearing stone fruit.

Under the conditions of nature, this increased fruitage would by no means compensate for the loss of the protective stony covering, for the seed unprotected by its coat of mail would be at the mercy of any bird or animal or insect that attacked it.

There would probably be no representative of the stone fruit family in existence to-day were it

not for the protection afforded the seed by its hard and indigestible covering.

Regardless of animate foes, the seed would perish from the effect of the sun, wind, rain, and frost, if denied protection.

And this is by no means a mere matter of inference. One of the great difficulties that attended the experiments which I have just narrated was the preservation of the stoneless seeds from one generation to another. It was found to be exceedingly difficult. Various insects, especially aphides, millipedes and eelworms, would get among them and quickly destroy them. Fungous diseases also attacked them. And for several years more than three-fourths of the seeds kept for planting were thus lost.

At a fairly early stage of the experiment I had large quantities of seeds in hand, for I was operating on an expansive scale in order to have wide opportunity for selection. Several hundred thousand plum seeds, all stoneless, were once placed in cold storage, at freezing temperature, as soon as they were gathered and cleaned. Some were placed in sterilized sawdust, and some in charcoal dust, and some in sand.

Another assortment, similarly packed, was kept in boxes in a cool shady place until the first of January, when all were planted. In both lots,

the seeds that had been kept in sand were in better condition than those preserved in the sterilized redwood sawdust. Those kept in charcoal differed little from the other lots. The ones in cold storage had suffered from blue mold more than the others, but both lots were in fair condition.

All were planted on the same day in rows side by side. The seeds that had been kept in cold storage germinated at once, and in a week were all practically above ground. The seeds of the other lot, which had come from the same trees, did not commence to germinate for about six weeks. Yet later in the season very little difference could be seen between the two lots; on the whole the cold storage seeds gave rather the poorer growth.

Further Improvements of Method

An even better method of preserving the seed was presently developed, and I was finally able to preserve the stoneless seeds almost as securely as if they had their original protective covering.

My new method consists in washing the stoneless seeds in clear fresh water when first removed from the fruit; immersing them for a few minutes in a weak solution of "Bordeaux mixture" (sulphate of copper and limewater),

then rinsing for a brief period in fresh water, and placing them in damp sawdust that has been sterilized by boiling, care being taken that the sawdust is barely moist, not wet. The box containing the seeds is placed on the north side of a building, in a cool, shady place, and examination is made from time to time to see that the seeds do not become too dry or infested with insects or mold.

If treated in this way, the seeds are practically all saved; they may be planted out of doors like other plum seeds, and they will germinate promptly.

It is obvious that a seed requiring such careful treatment to preserve it all the winter would stand small chance of being able to perpetuate its kind in a state of nature. But, on the other hand, it must be admitted that it is well worth while to give the amount of attention required to the preservation of these seeds, in view of the enhanced value of their product.

It will be understood, however, that the average fruit grower will not be required to concern himself about the seeds, as his orchards will be propagated by grafting in case of this fruit as is customary with all orchard fruits.

There can be little doubt, then, that the time is almost at hand when all our plums will be

THE ORIGINAL AND THE FINISHED PRODUCT

This picture shows the wonderful contrast in size between the original wild, partially stoneless, plum and one of the perfected stoneless prunes. Many generations lie between the two, yet the essential character of partial stonelessness that gave the little plum its only value has been retained in the remote descendant, while the strains of numerous cultivated plums have been bred in, so that the offspring of the dwarf plum is now large in size and of fine quality of flesh.

grown without stones, since the experiment of removing the stones from a large number of varieties can now be followed up without great difficulty.

The pioneer work has been done, and the cross breeding of my best present varieties of stoneless plums, to secure all the desirable qualities of any existing plum, may readily be effected.

Even though the fruit should not be of better quality in other respects than that which it supplants, the fact that the elimination of the stone permits an increased abundance of fruit, to say nothing of the value of the stoneless fruit itself, will offer an inducement that the progressive fruit raiser will find conclusive.

It should be added that the plum which has been induced to vary in the matter of seed production, is not always content merely to have cast out the stone but sometimes tends to eliminate the seed itself.

The Seed Also Must Go

One of my stoneless plums has nothing but a jellylike substance to take the place of the seed. It is probable that plums actually seedless as well as stoneless will prove favorites with some fruit growers.

Of course plums that present this anomaly cannot be propagated from the seed. But in this regard they do not differ from a number of cultivated plants, the banana and the sugar cane, and many others. And for that matter it must be recalled that very few orchard fruits are reproduced from the seed. The favorite varieties of apples and pears are so blended that they do not breed true from the seed. If you were to plant the seed of a Baldwin apple, a Bartlett pear, or a Sugar prune, there is only the remotest chance that you would produce a seedling that would resemble the parent.

Yet apples and pears and prunes are propagated year after year by means of buds and grafts. The same method of propagation would of course suffice for seedless plums.

It would still be possible, however, to produce new varieties of seedless plums by using the pollen of these varieties to fertilize the flowers of other plums that were stoneless but not seedless.

The seedlings from such a cross would tend to vary in successive generations, as all hybrids do. A certain number of the offspring of the second and later generations would doubtless be seedless, and it would thus be possible to develop

new varieties of seedless fruit from a parent stock that is itself incapable of producing viable seed.

The stoneless hybrids already produced represent almost every color of the plum—white, pale yellow, orange, scarlet, crimson, violet, deep blue, almost black, striped, spotted, and variously mottled. They vary indefinitely in quality. Some of them are of abnormal size. They ripen from the middle of June until Thanksgiving.

So the stoneless plum already constitutes a new race having numberless varieties, and the possibilities of further improvement are limitless.

In producing seedless fruits we are simply hastening their evolution for the benefit of man.

THE ROYAL WALNUT

Speeding the Growth of a Leisurely Tree

IF on visiting my grounds you were to notice two trees, one ten times as large as the other, growing side by side, you would perhaps be surprised to be told that the two are of the same age and grew from seed of the same parent. And it perhaps would not greatly clarify the matter in your mind to be told that these are varying individuals of a remarkable hybrid known as the Paradox Walnut.

But probably your interest would be aroused in a tree that could show such diversity of progeny.

The tree in question was developed more than thirty-five years ago. One of its parents was the native California black walnut tree; the other parent was the European tree usually called the English walnut, but with somewhat greater propriety spoken of as the Persian or soft-shell walnut.

A SIXTEEN-YEAR-OLD "ROYAL" WALNUT

At sixteen years of age, the new "Royal" Walnut trees were sixty feet in height and as much in breadth of branches—the trunk being two feet in diameter at eight feet from the ground. Meantime English walnuts on the opposite side of the street averaged only eight or nine inches in diameter, and had a spread of branches only about one-quarter that of the youthful "Royal." This variety originated from a cross of Juglans Nigra and Juglans Californica.

The European tree had been introduced in California a number of years before the time of my experiments, where it thrives and produces abundant fruitage. I had heard of a supposed natural European hybrid walnut, and I determined to make the experiment of fertilizing the flowers of the California species with pollen from the Persian.

The experiment itself presented no particular difficulties and the results were of a striking character.

The nuts that grew from the hybridized flowers were to all appearance unchanged. This, of course, is quite what might have been expected, for the influence of foreign pollen on the ovum of a plant manifests itself in the innate qualities of the seed, and not in the exterior qualities of the fruit immediately produced. But when the hybrid nuts were planted the following season, a part of the seedlings that sprang from them showed at once the effects of the intermingling of racial strains.

As compared with seedlings of either the California or the Persian walnut, they manifested an enormously enhanced capacity for growth. Indeed, they sprang forward at such a rate as presently to totally dwarf their pure-breed relatives.

The phenomenal growth of these hybrid trees continued year after year. The tree so far outstripped all competitors in the matter of growth that it might fairly be said to represent a new type of vegetation.

On this account, and in recognition of sundry other anomalies, I named them Paradox.

At sixteen years of age these trees were sixty feet in height and as much in breadth of branches, the trunk being two feet in diameter at about four feet from the ground. Meantime English walnuts on the opposite side of the street averaged only eight or nine inches in diameter at thirty-two years of age, and had a spread of branches only about one-fourth that of the youthful Paradox.

In addition to its quality of rapid growth, the Paradox has wide-spreading branches with a tendency to droop. It makes a beautiful shade tree. The leaves are of extraordinary length, sometimes measuring three feet, although usually only about half that. Another curious characteristic is that the foliage has a delicious apple-like fragrance, of which the foliage of the parent tree gives no suggestion.

These anomalies of growth and foliage show the mingling of racial strains. A further result of this mingling is shown in the fact that the

hybrid tree produces very few nuts. It is obvious that the two strains brought together are so variant that their progeny is made relatively sterile. The sterility is not absolute, however, for the few nuts produced germinate readily if planted.

But another anomaly manifests itself in the characteristics of the seedlings thus produced; for these are the ones that show such extraordinary variation in size.

In the same row, as already intimated, there will be bushlike walnuts from six to eighteen inches in height side by side with trees that have shot up to eighteen or twenty feet; all of the same age and grown from seeds gathered from a single tree. This rate of growth continues throughout life, and the fraternity of dwarfs and giants has been a puzzle to European and American laymen and botanists alike.

These second generation hybrids vary as much also in regard to foliage and general characteristics of form and development as in size. Some resemble the California walnut, others the Persian ancestor, and there are scores of variations, the manner of growth of some of which—notably those that trail their limbs along the ground like a gourd or squash—bears scant resemblance to that of any walnut. From this

WOOD OF THE "ROYAL" WALNUT

It might naturally be supposed that the "Royal" would produce a soft wood like that of most quick-growing trees. Such is not the case, however. The wood is harder than that of the black walnut, and has the beautiful walnut color and grain shown in the photograph print opposite.

extensive variation, it has been possible to select trees of even more rapid growth than the second generation hybrids, and the field seems to be open for the production, through selection in successive generations, of trees of still wider diversity of form and growth. Curiously enough the wood of the Paradox walnut is exceedingly hard, even harder and more close-grained than that of any other walnut. This is surprising in view of the rapid growth of the tree. Ordinarily trees that grow rapidly have soft wood, as every cabinetmaker knows.

The Paradox further justifies its name by producing a wood that has great firmness of texture (superior in this respect to all other walnuts) and is well adapted to take on a cabinet finish.

I had planted a row of these trees on one side of an eighty-foot street here in Santa Rosa, and, after making a few years' growth, the street was made impassable and the trees had to be removed.

All in all the production of the Paradox hybrid, and the development of a race of hardwood trees of exceedingly rapid growth, constitutes a genuine triumph in tree culture. A tree that grows to the proportions of a handsome shade tree and furnishes material for the cabinet-

maker in six or eight years, has very obvious economic importance.

The Royal Walnut

At about the time the Paradox was produced, I undertook another series of hybridizing experiments with walnuts that resulted in a tree scarcely less anomalous.

These experiments consisted of the mating of the California walnut with the black walnut of the eastern United States. The latter tree produces perhaps the finest cabinet wood grown in America, but it has almost disappeared from our eastern forests owing to the rapacity and lack of foresight of the lumberman. The California and eastern walnuts are rather closely related, yet the divergence is sufficient to give the hybrid a character markedly different from either parent.

In some respects this hybrid, which was christened the "Royal," showed characteristics analogous to the Paradox. It had the same tendency to extraordinary rapid growth, and in subsequent generations it showed to a certain extent the same tendency to produce a varied company of dwarf and of giant progeny. There was also a considerable variation in foliage, although not the extraordinary diversity shown

by the second generation seedlings of the Paradox.

In one important respect, however, the Royal hybrid differed fundamentally from the other. Instead of being relatively sterile, it exhibited the most extraordinary fecundity. The first generation hybrids probably produce more nuts than any other tree hitherto known. At sixteen years of age one of these trees produced a harvest of nuts that filled twenty apple boxes, each about two feet long by one foot in width and depth, and in one year I sold more than a thousand dollars' worth of nuts from a single tree.

The nuts themselves are closely similar in appearance to those of the parent trees, but are individually larger. Unfortunately seedlings grown from the nuts cannot be wholly depended upon to reproduce all the good qualities of their hybrid parents. Like most second generation hybrids, they tend to "throw back" to the divergent grandparent strains.

To propagate the race extensively, therefore, it is advantageous to adopt the well-known method of grafting or selection of the strongest growing seedlings.

It has been found that rootstocks of the Royal hybrid furnish very valuable stocks on which to graft the English walnut in California. On most

"PARADOX" WALNUT WOOD TWO INCHES IN DIAMETER EACH YEAR

The cross section of a "Paradox" Walnut trunk, pictured opposite, shows the annual rings of the tree, marking its yearly growth. The photograph is made exact size, and it will be noted that some of the markings are an inch apart, thus showing that the tree increased in diameter two full inches within the year. On good land an increase of four inches in circumference is usual.

soils a tree grafted on this hybrid will produce several times as many nuts as a tree of corresponding age growing on its own roots. The trees are also much less subject to blight when they are thus grafted.

It may be well to state here, as a matter of history, that the two first hybrid walnuts ever produced by the hand of man were first produced on my own grounds and first named, described, and introduced by myself.

Grafting the Walnut

The importance of the new walnut and the fact that it may best be propagated by grafting makes it desirable to add a few details as to the method by which grafting is effected; for in the case of the walnut the process is far more difficult than with ordinary fruit trees.

Grafting the walnut is not, indeed, as difficult as grafting the pecan or the hickory, with both of which species the process was until recently found impossible of accomplishment. In this regard the walnut is rather to be likened to the fig, both being difficult to graft, yet not presenting insuperable difficulties for the skilled operator.

Persons who first attempted to graft the walnut in California often failed four times out of

five; and budding was even less successful. But the importance of the subject led to a careful study of methods, and to-day grafters who thoroughly understand their work are so successful that they scarcely have more than two or three failures to hundred successful grafts.

To attain such success, however, it is necessary to attend carefully to the various stages of the process. The grafting should not be attempted until quite late in the season; just after the buds begin to start is the most opportune moment. Hard wood should in all cases be selected for grafting; the pithy tips are utterly worthless for this purpose. Some grafters claim that only about two cions should be used from the base of the last year's growth where the wood is very firm.

Of course the principle of fitting the inside bark or cambium layer of stock and cion accurately together applies here as in the case of every other tree. Further details of the method will be given in a subsequent chapter, where the special methods of grafting and budding will be more fully examined. It suffices for the moment to emphasize the fact that these methods of propagation are as advantageous in the case of the walnuts, whether hybrid or of pure strains, as in the more familiar case of fruit trees.

Of course the stocks on which to graft must be grown from nuts, and I have already pointed out that the seedlings are likely to show diversity. But all that is necessary is to plant the seeds rather thickly, and then to save the seedlings that show the best qualities.

Starting a Walnut Orchard

A practical method of producing a permanent and profitable orchard with a foundation to last for a century, is to plant some seeds of the Royal hybrid in groups of three or four at intervals of fifty feet each way. By the end of the first season the strong growers will have asserted themselves, and the others can be weeded out. There will almost surely be at least one good tree in the group. Failing that, there will be other groups in which there are extra seedlings of good quality that may be transplanted.

The seedlings should be allowed to grow for four or five years, the ground about them being cultivated and may be used for crops of corn, potatoes, beans, or pumpkins, but preferably not sown with grain, lest the growth of the trees be checked.

At the end of five or six years there should be a fine walnut orchard with trees having trunks three to six inches in diameter.

Now the stock is ready for grafting. The stock branches selected for this purpose should not be over two or three inches in diameter. The cions grow rapidly and an orchard produced in this way surpasses all others. Its trees have a natural black walnut vigorous system of roots, with undisturbed tap root. A year's growth has been saved by not transplanting, and a start equivalent to the growth of several years has been gained by using the faster-growing hybrid.

So the English walnut grafted on this stock becomes a producing tree at a very early age, and an orchard of English walnuts thus grafted is worth perhaps at least twice as much as one on its own roots.

The tree thus grafted has not only the advantages mentioned, but it is more wide-spreading and therefore more productive than the original tree; and the spread of limb is duplicated by the root system, which thus insures a good supply of nourishment and the capacity to produce large crops even in dry seasons.

We have seen that the hybrid walnuts of both the Paradox and the Royal types have the peculiarity of producing trees of quick growth and gigantic stature in the first filial generation, and a mixture of dwarfs and giants in the second generation.

The Strange Traits of Hybrids

The tendency to surpass their parents in size is a characteristic that is very commonly manifested when plants of different species are hybridized. It is a familiar and now well-recognized fact that the crossing of diverse strains of living creatures, plant or animal, tends to result in what for lack of a better term is usually described as increased vitality.

It would appear as if the conflict of new tendencies so stimulates the cellular activities as to give them an unwonted capacity for reproduction.

In this case we are not concerned, as we were in some of the other hybridizing experiments already examined, with the prepotency or dominance of the qualities of one parent. Instead of this there is a distinct blending of characteristics so that the new product is in many respects intermediate between its parents in matters of foliage and fruit. But in growing capacity it far surpasses them both.

Thus we have produced, as the offspring of the slow-growing English walnut and the not very rapidly growing California species, a tree that grows so rapidly as presently to tower far above either of its parents.

VARIATION IN HYBRID WALNUT LEAVES

With this work, as with all other plants, strict attention is paid to the selection of those seedlings which have the largest and best leaves, and the best leaf formation. Many seedlings, promising in other respects, have faulty leaves, and promptly go to swell the bonfires of rejected plants.

As to form of leaf and fruit the hybrid may resemble one parent in one direction and the other parent in another. The leaf of the Paradox walnut, for instance, more closely resembles the leaf of the English parent. The outside appearance of the Paradox nut is also similar to that of the English walnut. But on breaking the shell we find that it is thick and strong like the shell of the American species, and the kernel is relatively small, quite different in form as well as in flavor from that of the English walnut.

It cannot be said that anyone has a very clear notion as to precisely what the changes are that give to a hybrid race this enhanced vitality. But this mystery is after all only part of the great all-pervading mystery of heredity, which in turn is merged with the mysteries of life processes in general.

Why Some Are Dwarfs

What I shall consider a little more at length here, however, is the conduct of the seedlings of the second generation grown from either the Royal or the Paradox hybrids.

How does heredity explain the observed fact that some of these are dwarfs that can by no process of urging be made to attain anything like the average stature of walnuts in general, whereas others, sprung from nuts grown on the

same branches, are giants that surpass even their hybrid parent, not to mention their moderate-sized grandparents? The fact of this diversity is unquestionable. It affords a surprise to all who inspect the trees of this strangely diversified fraternity.

But how explain it?

A clue to the explanation is gained when we learn that a California walnut, which, it will be recalled, was a parent form in each of the hybrid strains, is a tree showing great variability in the matter of size when growing in a state of nature. In the northern and central parts of California it is usually a large spreading tree, often with gracefully drooping limbs. But farther to the south it becomes a mere shrub, and on the mountains and hills about Los Angeles it is only a bush. The nut diminishes in size correspondingly until, in Texas and Mexico, it is scarcely larger than a pea.

When growing still farther to the south, in New Mexico and Texas, the black walnut is sometimes classified as a different species.

It appears to me, however, that these dwarfed southern forms are only varieties that have acquired different characteristics through the influence of what for them has proved an unfavorable environment. In any event there is no

reason to doubt that the dwarf form and the relatively large one are descended from the same original stock, though doubtless divergence has gone on through numberless generations.

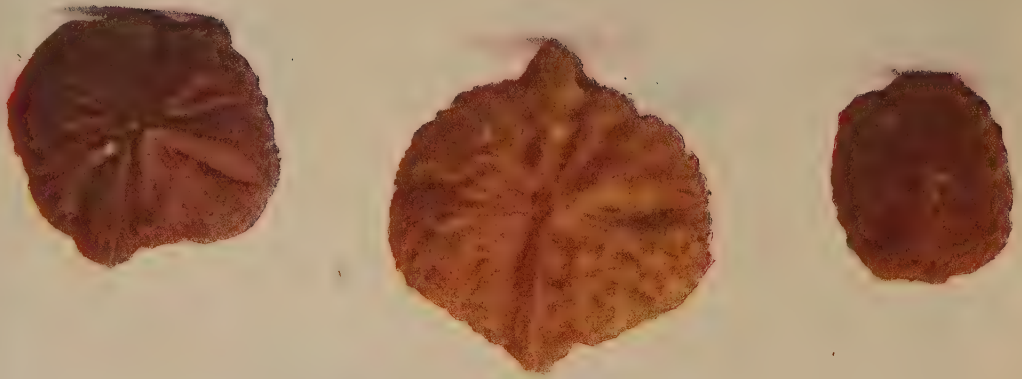
Meantime the English or Persian walnut, the other parent of the Paradox, is also a variable tree. In its native home it is very small, and even the cultivated variety cannot be depended upon to reproduce a given racial strain when grown from the seed.

It is obvious, then, that the tendency to dwarfness, which appears in such conspicuous fashion in some of our second generation hybrids, may be accounted for as reversion to dwarfed ancestral strains in both parents in the case of the Paradox and of one parent in the case of the Royal.

The tendency to grow relatively large prevailed in the strains of walnuts that were used in my hybridizing experiments, and the prepotency or dominance of this tendency is clearly shown in the hybrids of the first filial generation. But the latent tendency to dwarfness, which in the Mendelian phraseology would be termed a recessive trait, is able to reassert itself in a certain number of the offspring of the second filial generation, causing these to "throw back" to their dwarfed ancestors in the fullest measure.

HYBRID WALNUTS

In our catalog of 1894 *a picture was given of the first nuts ever borne by the "Paradox" walnut, the celebrated hybrid between the Persian walnut and the California black walnut. These nuts, as would be expected, are a complete combination of the two species in every respect; one was tested, the others planted. The variations appeared in due course, as this picture showing the fruit of later generations amply testifies.*



The capacity for large growth has been absolutely left out of their individual make-up.

In the Mendelian phrase they are pure recessives; or, using the more technical terminology, they are "homozygous" as to the heredity factors or determiners of the unit character of dwarfness.

The reader may or may not feel that the new terminology adds to our comprehension of the phenomena. But in either case the fact of the appearance of the dwarf specimens of the second generation among the hybrids is at least in a sense explained by our knowledge that there were dwarfs in their ancestry.

How Account for the Giants

But while we are thus supplied with a more or less satisfactory explanation of the appearance of the dwarf hybrids, the colossal companions of the same generation are as yet unaccounted for.

It is a familiar fact, as just pointed out, that hybrids of different species do tend to take on new capacities for growth. But what hereditary warrant have the upstarts for thus outdoing their parents? So far as we are aware, there is no record of a pure-bred walnut of any of the three species involved that ever showed such capacity for rapid growth or such propensity to

continue growing until it attains colossal proportions as the hybrids manifest.

There is no recorded or observed ancestor to whom we can appeal in explanation of the development of these new races of giants.

As yet we are not denied at least a hypothetical explanation that may perhaps account for the observed colossal growth of these new races of trees. The explanation demands that we go back in imagination through very long periods of time, and consider the ancestors of our walnuts not merely for hundreds of generations but for thousands or perhaps for millions of generations.

It is necessary, in short, to trace backward the ancestral history of the walnut to those remote epochs when the primordial strain from which the present trees have developed grew in tropical regions, and, in common with tropical vegetation in general, doubtless acquired the habit of luxuriant development.

It is permissible even that we should place in evidence the exuberant vegetation of that remote geological era known as the Cretaceous Age.

In that time, as the records in the rocks abundantly prove, the conditions of climate now restricted to the tropics prevailed even in the temperate zones, and the vegetable life was char-

acterized by the abundant production of colossal forms.

In successive ages the climate changed, and it became necessary for the plants that were unable to maintain existence under the changed conditions to adapt themselves in size and in structure to a less bountiful supply of foodstuffs drawn from both soil and air; for the soil of the temperate zone is relatively arid, and the air probably became progressively less rich in carbon, owing to the permanent storage of vast quantities of this substance in what ultimately became the coal beds.

So it came about that all the descendants of the colossal plants of the Cretaceous Era formed races that were dwarfs by comparison. Here and there a straggling species, like the California redwoods, preserved a reminiscence of its imposing heritage. But in general the trees that make up our forests in the temperate zone are but insignificant representatives of a lost race of giants. These, then, are the remote ancestors that may be invoked in explanation of the rapid growth and relatively gigantic stature of our hybrid walnuts.

In this view the exceptional growth of these hybrids betokens reversion to remote ancestral strains that for countless generations have not

A GRAFTED WALNUT TREE

The selected varieties of walnuts do not breed true from the seeds, so it is necessary to graft them in making commercial orchards, just as in the case of the orchard fruits. This is a typical specimen grafted on the "Royal" black walnut.

been able to make their traits manifest, but which have always transmitted these potentialities as submerged and subordinated tendencies. The admixture of the divergent racial strains—one from Europe, the other from California, or in the case of the Royal, from origins separated by the breadth of a continent—sufficed to bring together factors of growth that for all these generations had been separated, and the atavistic phenomenon of a giant walnut came into being.

Thus interpreted, the case of the big walnut is not dissimilar to the case of our white blackberries or to that of the fragrant calla.

In each of these instances, as in that of numberless others that we shall have occasion to examine, a mixture of racial strains brings about a reversion to the structure or quality of a remote ancestor.

In the case of the walnuts we have had occasion to go back a few thousand generations farther than in the other cases, but there is ample warrant for believing that nature sets no limit on the length of time throughout which a submerged character may be transmitted, with full possibilities of ultimate restoration.

We shall have occasion to examine further evidence of the truth of this proposition, drawn from a quite different field, in a later chapter.

Here, for the moment, we may be contented merely to place our colossal walnuts in evidence.

Towering above their dwarf blood sisters, they present a vivid object lesson in heredity that appeals directly to the senses and strangely stimulates the imagination.

Nature sets no limit on the length of time throughout which a submerged character may be transmitted.

THE WINTER RHUBARB

Making a Crop for a High-Priced Market

MORE than one enthusiast has declared that the most important garden vegetable that has been introduced to the world in the past half century is the giant crimson winter rhubarb.

This no doubt is an overestimate, if for no other reason than that it overlooks the Burbank potato or the thornless blackberries or the new series of giant shipping plums. Still, there is no question that my winter rhubarb has proved to be of great economic importance. Although introduced quite recently, it has already made its way to all quarters of the globe, and has proved of unusual value in regions where no other rhubarb had hitherto been, or could be grown.

At the Cape of Good Hope, for example, efforts to grow rhubarb had been made for two hundred years at least, and always without success; but the new variety proves an especially sat-

isfactory crop there, as elsewhere in warm, arid climates. The plant has aroused very unusual interest in conservative Great Britain, where the older varieties thrive and have been extensively grown, specimens having been obtained direct from my plantation by Robert Holmes, a member of the Royal Horticultural Society, and others. The royal gardens of England are now supplied with it.

Meantime the Emperor of Japan and the King of Italy obtained it directly from my gardens, and the plant has been taken back to its original home in New Zealand, from whence came the material for its production, and in its improved or, one might better say, metamorphosed condition, it now finds favor there, whereas its ancestral form was justly regarded as a plant of no importance.

The Qualities of the New Rhubarb

It must not be supposed that this widely extended approval of the rhubarb is dependent on any mere caprice. It is based on qualities of the most enduring and substantial character, otherwise it would not have been possible to plant thousands of acres of this crop in California and to find a ready market for the entire product in the eastern United States. In point of fact, so

eager has been the market that the rhubarb has been quite often called by its growers the "king mortgage lifter." Many substantial fortunes have been made by growing it here in California and shipping it to the eastern States during the holiday season when fruits and green vegetables are relatively scarce.

It retains, as to general appearance, the aspect of the usual stalk of the familiar rhubarb or pieplant of the eastern vegetable garden. But the stalks are of a characteristic rich crimson color, and as brought to the table the sauce made from them is not only delicious in flavor, suggesting the strawberry and raspberry, but it is quite devoid of the stringiness or fiberlike texture and the disagreeable "ground taste" of the ordinary pieplant.

Many people who have hitherto regarded pieplant as a plebeian dish to be avoided are enthusiastic in the praise of the new product.

The crimson winter rhubarb produces not only far larger stalks than the old New Zealand prototype, but at least ten times as many of them to each plant. The stalks begin to appear in great abundance early in September and continue to produce a product of unvarying quality for eight to twelve months together—in California throughout the entire year—instead of

for a few weeks in the spring. So the popularity of the winter rhubarb from the standpoint of the grower as well as of the dealer and consumer, is not hard to understand.

It may be added, as further evidencing the unusual qualities of the new plant, that it grows in almost any soil, although giving quick response to good conditions of cultivation like the older varieties; that it propagates readily from root division and under these circumstances remains altogether true to the perfected type; and that it is unusually productive and requires no unusual attention, so that any amateur may grow it in his garden even more readily than he grows the ordinary rhubarb.

It must be understood, however, that the plant cannot thrive in latitudes where it is buried under snow, as the steady production of leaves appears to be essential to its very existence.

In the colder parts of California it does indeed cease to grow actively in the heart of winter, but even then it submits to adverse conditions reluctantly, if the phrase may be permitted; that is, it stops putting forth new leaves only when the conditions are exceedingly unfavorable and immediately resumes new growth when the slightest change for the better in the weather occurs.

The Origin of the Winter Rhubarb

The importance of the new plant, and its wide departure from the traditions of the rhubarb family, might lead one to suppose that the production of the new variety had been a task of great difficulty. Perhaps from the standpoint of the average plant breeder it could hardly be said that its creation was altogether easy; yet compared with some of my other plant developments the production of this one was at least relatively simple.

The original stock from which the new variety was developed came to me from the antipodes. It was sent by the firm of D. Hay & Son from Auckland, New Zealand.

The first two or three shipments were lost, as the plants died on the way, but at last I obtained half a dozen very diminutive roots that showed some signs of life. These, as anticipated, produced stalks during the winter instead of following the conventional rhubarb custom of putting forth stalks for only a few weeks in the spring.

The stalks of this original winter rhubarb, however, were very small—about the size of an ordinary lead pencil—and certainly not worth cultivating for immediate use, as they would

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A TYPICAL PLANT

This picture shows a single plant of the Giant Winter Rhubarb that grows to the height of almost four feet. The handsome crimson stalk contrasts finely with the green foliage. The quality is far superior to any other rhubarb, and the production of the stalks is perpetual throughout the whole year. The flavor is much more like that of strawberries than of the old-style rhubarb.

have proved quite unmarketable. The plant was admitted to have no great value in New Zealand. Indeed, in point of value the imported plant bore no comparison with ordinary pieplant of our gardens.

It was solely and exclusively the quality of winter-bearing that made the plant appeal to me and suggested the possibility of developing from it a valuable addition to our list of garden vegetables.

My original stock of half a dozen plants soon increased to a hundred or more. These plants produced seed abundantly in successive years, and all this seed was carefully planted and the seedlings that grew from it, to the number of hundreds of thousands, were closely examined and tested as to various desirable qualities.

From among the thousands I was able to select here and there a plant that showed exceptional qualities of growth, standing well up above its companions of the same age. Of course selection was made of the plants showing this exceptional virility, and in the course of a few years I had thus developed, by persistent selection, a race of plants that grew with extreme rapidity, and to a size, by comparison, quite dwarfing that of the original parent stock.

These fast-growing descendants of the New Zealand plant had not only the desirable qualities of texture and flavor of leafstalk already referred to, but they retained and advanced upon the tendency of their ancestors to grow constantly throughout the year. This anomalous tendency, rather than the improvement in the other qualities of the plant, is obviously the one that requires explanation. Remarkable improvement in size and in other desired qualities, through selection, is a more or less familiar method of plant development.

But the production of a race of pieplant that departs radically from the most pronounced and characteristic trait of the rhubarb family, namely brief period of bearing, is something that requires explanation.

A clue to the explanation is found when we recall that the plants were sent me from a region lying on the other side of the equator. The plants were exceptional even there in that they had shown a tendency to bear—that is to say to produce small juicy leafstalks—during the cold season. Through some unexplained freak of heredity or unheralded selective breeding they had developed a character that had enabled them to put forth their leaves much earlier than is customary with all other races of rhubarb.

The difference was only a matter of weeks, and was of no greater significance, perhaps, than the observed difference in time of bearing between different varieties of other vegetables and fruits. Everyone knows that there are early and late-bearing varieties of most commonly cultivated vegetables and fruits — summer apples and winter apples furnish a familiar illustration.

Perhaps some one had discovered a root of rhubarb that chanced to have peculiar qualities of hardiness, and had propagated it until he had a variety that began bearing while the relatively mild New Zealand winter was still in progress.

But this is only the beginning of the story. The sequel appears when we reflect that the season that constitutes winter in New Zealand is coincident with the summer time of the Northern Hemisphere.

So when we say that the crimson rhubarb was productive during the winter in its original home, this is equivalent to saying that it had the habit of bearing during our summer time. Transplanted to California, the New Zealand product continued to put forth its stalks, quite in accordance with its hereditary traditions, during what, according to its ancestral calendar, was the winter season, although the climatic conditions that now surrounded it were those of summer.

The Influence of Environment

But meantime this plant, like every other living organism, was of course subject to the directly stimulative influence of its environment. Its hereditary traditions had developed what we may speak of as an instinctive tendency to grow at a given time of year regardless of climatic conditions; but they had also given it an equally powerful tendency to respond to the stimulus of cold weather, and to become productive not merely in the *season* of winter but under the *climatic conditions* of winter.

In other words, the combined influences of heredity and of immediate environment were here as always influential in determining the conditions of plant growth.

But, whereas in New Zealand the environment of winter—characterized by cold temperature—coincided with the calendar months of June, July, and August, in the new environment of California the conditions of winter were shifted to the calendar months of December, January, and February. So the two instincts, one calling for productivity in June, July, and August, and the other for productivity during cold weather, were now no longer coincident, but made themselves manifest at widely separated seasons, thus

perhaps aiding in the production of a perpetual rhubarb.

So the net result was that, merely through the retention of old instinctive habits under the transformed conditions imposed by migration to the Northern Hemisphere, the winter-bearing rhubarb of New Zealand was transformed, by most careful and persistent selection, into a summer and winter-bearing plant in California. And inasmuch as there are no sharp lines of demarcation as to just when the pieplant begins and ends bearing, the two seasons tended to merge, with the practical result that some of these plants became all-the-year bearers.

The Power of Habit

Possibly the use of the words habit and instinct as applied to a plant requires a few words of elucidation.

We ordinarily take the habits of a given plant so much as a matter of course that we are prone, perhaps, to overlook their close correspondence with the habits of birds and animals and other animate creatures. Yet a moment's consideration will make it clear that we may with full propriety speak of the fixed or regular "habits" of plants, and that there is no logical reason why we should not speak of them as being

determined by "instinct," which after all suggests only the spontaneous response to environing conditions, present or reflected through heredity.

And the force of the various instincts or habits, in the case of a plant, as in the case of birds and animals, is overwhelmingly powerful and quite beyond the possibility of change in any given generation.

To cite a single illustration from the case in hand, every gardener knows that he cannot by any process of cultivation make the ordinary rhubarb plant change its fixed habit of spring production. No amount of coaxing and no manner of soil cultivation or fertilization can take from the rhubarb the impelling force of the hereditary tendency to put forth its stalks in the spring time rather than in summer or fall or winter.

And a similar fixity of habit characterizes, in greater or less measure, most other familiar cultivated plants. Artificial selection has extended the season in certain cases, and early or late-bearing varieties have been developed as already noted; but for each variety the habit of producing at a given time of year is one of the most fixed and—as regards any given generation—unalterable of tendencies.

Illustrations from Birdland

Perhaps the all-importance of this inherent tendency to gauge habits in accordance with the calendar will be more clearly apprehended if we cite another illustration from the organic world.

Take the migrations of birds as a familiar instance. If you watch the birds at all, you have doubtless noted that the migrants that come to temperate regions from the tropics arrive each spring in your neighborhood at a date that you may fix in advance with almost entire certainty.

The hardier birds, to be sure, such as the robin, the bluebird, and the meadow lark, retire before the blasts of winter somewhat unwillingly and they begin their northward migration at a period that may vary by a good many days or even weeks according to the forwardness or backwardness of the season. But the coterie of tender birds—orioles, vireos, wood robins, tanagers, flycatchers—which spend the winter in the region of the Equator, must begin their northward migration without regard to the climatic conditions, inasmuch as their winter home is a region of perpetual summer.

They start northward merely in obedience to an instinctive time sense that has been implanted through long generations of heredity, and they

move across the zones with such scheduled regularity as to reach any given latitude almost on a fixed day year after year.

In Massachusetts or New York or in Ohio or in Iowa, for example, you will find the last flight of migratory birds, comprising the various species of wood warblers and vireos, the orioles, and the scarlet tanager, appearing between the tenth and fifteenth of May each year, without regard to the advancement of the season.

And a few months later you will note, if you are observant, that these and the other migrants disappear in the fall, having taken up their return voyage at about the same calendar period year after year, although in one season the September days may be as hot as August and in another season chill as November.

Countless generations of heredity have fixed in the mechanism of the bird's mind the instinct that impels it to migrate at a fixed season; and no transient or variable conditions of the immediate environment can alter that instinct, even though, in a given case, its alteration might be vastly to the advantage of the individual.

Even Unto Death

As proving the latter point, and as further illustrating the force of the instinctive time sense

under consideration, let me recall the case of the martins to which reference was made in an earlier chapter—the case in which these birds starved to death because in a particular season drought prevented the hatching out of their insect food.

Everyone knows that the martin is a bird of very swift and powerful flight. Its estimated speed is more than a mile a minute, and it habitually remains hour after hour on the wing. It was easily within the capacity of the martins that starved to death in New England to have shifted their location at the rate of more than a thousand miles a day.

And assuredly within half that distance, probably within two or three hundred miles at the most, they would have found an abundant supply of food.

Now the season at which the martins actually starved was August; only a few weeks, therefore, before the time of their regular autumnal migration. Had the birds lived another month they would instinctively have begun a long journey to the south, and a single night's flight would have brought them to regions where no doubt their food needs would have been abundantly supplied. From a human standpoint, it would seem only natural that the birds, deprived of food, should have begun their seasonal migration

a few weeks before the usual time; whereby their lives would have been saved.

Whoever understands the force of hereditary instinct will realize that such a departure as this was for the birds impossible.

The instinct of migration comes to the martins in September, not in August, or at least not in early August. The habit of migration is no more determined by any conscious judgment of the bird than is the habit of spring growth determined by a conscious judgment of the rhubarb.

The force of untold generations of ancestors impelled the martins to remain where they were, even though starvation was the penalty.

Wings they had, with which they might have sought and found a new environment where food was plentiful; but they were powerless to use the wings at this particular season, because the particular week had not arrived at which the hereditary clockwork of their organisms would strike the hour for migration. Taken by the race at large, it is better for the martins that they should not migrate until September; this fact had been established through the test of thousands of generations, and the result was registered indelibly in the organism of every bird. Were it possible to destroy the racial tradition in the interests of any single generation, the life

habits of the species would become so variable and desultory that racial continuity would be endangered.

So the individuals of a generation throughout a large region were sacrificed to a racial instinct which in the main was beneficial to the species. It will be clear, I trust, how this illustration bears directly on the case of our winter rhubarb.

Restoring Submerged Instincts

It could make no difference to the roots of this plant that they had been unwittingly transplanted from a land where winter comes in July to a land where that month betokens summer. The instinct of bearing at that particular season had all the force of the instinct that impels the bird to migrate at a given time; and this instinct could by no chance be repressed in a given generation, any more than the martins could make over their migratory instinct to fit a transitory condition.

But all this leaves quite unexplained the other fact, which bore so important a part in our story, that the New Zealand rhubarb when transplanted to California assumed a new habit of bearing during the cold season of the Northern Hemisphere which corresponded to the summer of its original habitat and therefore to a calendar

period at which its immediate ancestors had been accustomed to assume a condition of dormancy.

How is our theme of the power of instinctive habit to be made to coincide with this seemingly illogical departure?

Our answer is found, as it has been found in the explanation of other anomalies of plant development, in an appeal from the immediate ancestry of the rhubarb to the countless galaxies of its vastly remote ancestry.

In point of fact the rhubarb is, in all probability, a tropical plant that has but recently migrated to temperate zones—using the word recently in the rather wide sense necessary when we are dealing with questions of racial development under natural conditions. In other words, it is perhaps only a matter of a few hundred generations since all the ancestors of the existing rhubarb tribes were growing in a tropical temperature, and hence, like the tropical plants in general, were all-the-year bearers.

In more recent generations, this habit of perpetual bearing has been modified, in case of the rhubarb as in the case of nearly all plants of temperate zones, to meet the altered conditions of a climate in which seasons change.

To adapt themselves to this change of climate, plants were obliged to go into retirement in the

winter season, and natural selection preserved only the races that showed this adaptability of habit. Thus the common race of spring-bearing rhubarb, as we know it, was developed.

But the latent capacity to bear at all seasons—to live a fully rounded life throughout the year which may be considered the normal and inherent propensity of all living things, and which is observed to be the habit of tropical plants in general, was never altogether lost. Submerged generation after generation and century after century, the hereditary factors that make for perpetual growth were still preserved, capable, under changed conditions, of being resuscitated and of making their influence manifest.

The changed conditions came, in case of the rhubarb, when the plant found itself in the new environment of California.

New soil, new atmosphere, new climate—all these are stimulative. Then successive generations of the plants were bred from seeds, and we have already seen that the mixture of strains thus effected tends to have a disturbing influence on the life forces permitting new combinations of characters and resulting in the development of new forms.

We saw this in the case of the Shasta daisy and very notably in the case of the hybrid wal-

READY FOR SHIPMENT

The handsome appearance of the Crimson Winter Rhubarb adds greatly to the attractiveness of this "vegetable and fruit" in the market. We have given particular attention to the development of plants that will grow stalks of a uniform size, this being an obvious additional advantage in marketing the product. The color of the Winter Rhubarb gives it added attractiveness when it finally comes to the table.

nuts. We shall note the same thing again and again in connection with a multitude of other plants.

In the case of the rhubarb, the response was almost immediate. Artificial selection enabled the plants that manifested the atavistic tendency in largest measure to propagate their kind.

And, thus, in the course of a few generations —though not without making selection among hundreds of thousands of individuals — I was enabled to assist the plant to bring to the surface the long submerged tendencies that impelled it to grow fast, to grow large, and to grow perpetually.

No New Principle Involved

And thus the crimson winter rhubarb as it finally came to perfection in my gardens is accounted for. In developing it, no new principle was invoked, no new method even. I merely took advantage of opportunities afforded by the translation of the plant from one hemisphere to another, and aided the plant in putting forth potentialities that had long been repressed but which still stubbornly persisted as latent factors or submerged tendencies in the racial germ plasm.

Perhaps the matter seems rather complex as thus explained; and indeed all matters pertaining to living organisms are complex in the last analysis. But the methods of operation were in practice simple.

Granted certain conditions and certain hereditary tendencies; granted, in other words, the materials with which to work, it required only clear-eyed selection and patient waiting—the encouragement of some tendencies in the right direction and the suppression of other tendencies in the wrong direction—to produce the desired result.

Propagating the Winter Rhubarb

To make the story complete, however, it should be recorded that although the winter rhubarb was developed by mere selective breeding of a pure strain, yet the experiment was not carried forward without numerous tests of the hybridizing method.

From the outset the New Zealand plant was crossed with the native rhubarb, hoping thus to stimulate variability.

And, almost needless to say, variability was stimulated. The hybrid plants took on sundry forms and diverse habits. But it chanced that no one of these forms was an improvement on those

that were secured by selection from the pure New Zealand stock.

Nor did this New Zealand stock, even when developed into my new all-the-year bearer, prove capable of sure propagation from the seed. It can readily be propagated by dividing the roots or by cutting out little sections of the root containing a bud, so there is small necessity of development from the seed. But in this case, as with so many other cultivated plants, it is essential to use this method of propagation if we wish to have an absolutely fixed variety.

An obvious explanation would be that the original New Zealand rhubarb was of mixed racial strains. This, indeed, would account for its tendency to vary, and to contribute to its successful development in California. The interbreeding which produced the winter-bearing strain may have been done quite by accident in New Zealand, the plants that came to me embodying the germs of possibilities of development without further hybridizing.

Perpetual Bearing Now Fixed

It should be added, however, that even when grown from seed, the new winter rhubarb *always* manifests the tendency to perpetual bearing.

This one trait is fixed, though some of the other qualities of the plant are still variable.

Using the new terminology we may say that the tendency to winter-bearing is a unit character that is latent or recessive, and that the winter rhubarb has no factors of the opposite trait of limited bearing and therefore cannot revert so long as it is inbred. When crossed with the spring-bearing race, however, the offspring sometimes revert to the old habit, as might be expected.

As already noted, nothing so far has been gained by such crossing. Nor is there any necessity for the growth even of pure-bred seedlings. Propagation by root division answers every purpose and, thus multiplied, the new crimson winter rhubarb, in its perfected varieties, constitutes a fixed race and is a permanent acquisition to the list of garden vegetables.

It required only clear-eyed selection and patient watching—the encouragement of tendencies in the right direction and the suppression of tendencies in the wrong direction—to produce the result.

THE BURBANK CHERRY

The Explanation of a Double Improvement

"HOW many assistants have you in your orchard?" a visitor asked me.

And when I replied, "About a hundred thousand this morning, I fancy," my visitor looked quickly this way and that across my eighteen-acre Sebastopol farm, and then seemed politely incredulous.

"I don't see quite so many," he remarked. "In fact, I can see but eight."

"No," I said, "you don't *see* them; but you can *hear* them if you listen. They are mostly up there among the cherry blossoms. Notice how their wings hum as they go from flower to flower."

"You mean the bees?"

"Just so; the bees—they are my most important helpers at this season. I should get no cherry crop without them, and for that matter no plum crop, no apple crop, and very few

flower seeds. In fact, most of us who grow fruit would soon go out of business, or reduce our farms from acres to square feet, if it were not for the bee helpers buzzing about from blossom to blossom."

"But do you depend entirely upon the bees to pollenize your cherries?" my questioner continued.

"Not altogether. I am obliged to do some pollenizing, particularly at the beginning of an experiment, to make sure of the exact cross that I desire. But after the experiment is under way, the work is for the most part left to the bees. They operate, as you see, on a large scale, making a thousand pollenizing experiments where I could make one. And in the end the results of their work are highly satisfactory."

How Pollenization Is Effected

To illustrate the necessity for the aid of the insect helpers, it is well to show the method by which cross-pollenizing is effected when done by human hands.

A blossom is selected that is almost mature but has not opened, and is cut all around with a very thin, sharp knife, taking the petals about two-thirds the way down, thus amputating all the stamens, but leaving the pistil.

Pollen which has previously been collected upon a watch crystal from some open flowers is applied by lightly touching the finger to it, then to the stigma, taking care to cover the top of the stigma completely with the pollen.

This is a simple enough procedure, but it must be done carefully, as the number of tests that one experimenter can manage is limited.

Moreover, it is necessary, of course, in a case that calls for hand pollenizing, to mark the blossom with a tag of some sort, else there would be no record of the experiment, and no way of telling whether it finally proved successful. Again, it is usually desirable to remove other blossoms from the cluster in which the artificially pollenized one grows, to give a better opportunity for development of this individual.

If, finally, we are to make absolutely certain that no other pollen comes in contact with the stigma, thus guarding against the possibility of fertilization of the flower by other pollen than that intended, it may be desirable to tie a paper bag over the flower.

The latter procedure is not usually necessary, particularly if care has been taken to cover the stigma with pollen, as once this is done there is almost no danger that any foreign pollen will find lodgment. Moreover, the flower from which the

petals have been cut, as just described, will not attract the bees, and would almost certainly not be fertilized at all if our experimental pollenization should for some reason fail.

Time the Limiting Factor

But even when restricted to the essentials, the process takes time; and although some thousands of hand pollinations are done annually in my gardens and orchard, yet, as intimated, we try to leave the bulk of this work to the bees. Of course, these otherwise admirable helpers make no distinction between different varieties of blossoms, passing freely from one tree to another, regardless of the variety; but they usually confine their attentions on any given day to trees of a single species; that is to say, they do not ordinarily pass from cherry blossoms to the blossoms of the plum or almond, even if all are in season. They seem to prefer not to mix their sweets. So they do not distribute pollen to the wrong flowers as often as might be supposed.

Where pollenizing experiments are to be made on a larger scale, I sometimes place a branch of a cherry tree in full bloom among the branches of the tree of another variety, with which I wish to effect hybridization. The bees then transfer the pollen from the borrowed limb to the flowers

on the surrounding branches, and a thoroughly satisfactory cross pollination is often thus brought about, as anyone of any experience knows.

If a visitor who observes my cherry trees in the blossoming time chances to visit my orchards a little later, at the time of fruiting, he will probably be disposed to admit that my various methods of experiment have produced very satisfactory results. For the cherries that grow on my trees are the largest and most luscious, as well as the most abundant, that have ever been produced, and the visitor will perhaps be surprised to find many hundreds of cherries quite different in appearance sometimes growing on the same tree. This, however, is only the result of grafting.

Seedlings grown from seed produced on a single tree may vary widely, but the immediate fruit of any individual tree is fairly uniform, unless the tree has been grafted.

But trees on my farm always *are* grafted, so the phenomenon of diverse varieties of fruit on the same tree is a familiar one.

An Unstable Race

The cherry is at best a variable fruit. Like most orchard fruits, it can never be grown de-

THE GIANT CHERRY

A few years ago this fine black cherry was found on one of the branches of a cherry tree that is grafted with several hundred varieties. The "Giant" is one of the most productive of all cherries and no other surpasses it, either in size or quality. (Enlarged one-fourth.)

pendably from seed. But, of course, it is necessary in producing new varieties to work from seedlings, and from the standpoint of the experimenter who wishes to produce new varieties, it is fortunate that the tendency to vary exists. For, as our other experiments have taught, in the case of plants already described, it is only when a tendency to vary from a fixed racial type has been brought about by hybridization, or otherwise, that the material is furnished upon which the experimenter can build.

In the case of the cherry, all the familiar varieties are the result of hybridizing unconsciously in the past.

By working with the seed of any single existing variety, one secures plants of numerous types that suggest different possibilities of development.

The Ideal Cherry

In the course of these experiments, however, I have had occasion to bring together, through artificial pollenization, various standard varieties of the cherry, and, although it has not been found to be necessary to send to foreign countries, yet the stock with which I have worked represents races which have been developed in regions as widely separated as Russia, the eastern United States, California, and Japan.

It has been my aim to combine the desirable qualities of different races of cherries from these widely separated regions, and the task here, as in so many other instances, has chiefly consisted in persistent selection among multitudes of seedlings of widely diverse types.

The foundation stock with which I began chiefly was the variety known as Early Purple Guigne, crossed with the Black Tartarian; but in subsequent crosses the qualities of Russian, French, and American cherries and of numerous others were introduced, in an attempt to achieve the ideal cherry.

A familiar but notable characteristic of the cherry, in which it differs markedly from most other fruits, is its habit of ripening at the very beginning of summer, while many of the small fruits are not yet in blossom. This characteristic gives the cherry peculiar commercial value, as it comes on the market at a time when there is a scarcity of fruits.

It occurred to me many years ago that there would be a still greater advantage if a good cherry could be produced that ripened much earlier than any variety then known.

So early ripening was one of the first ideals at which I aimed. With that object in view it was natural to select for these early hybridizing

experiments specimens growing on trees that were observed to bear earlier, even if by only a few days, than other kinds.

To come at once to the sequel of the story, I was able after many years of experimentation to produce a fine, large, productive cherry that ripens about two weeks earlier than any variety before grown. This result was achieved by persistent selection, generation after generation, of specimens that manifested the early-fruiting character. But the full bearing of the story cannot be understood unless attention is given to the almost numberless complications that were involved.

Seeking Many Ends at Once

Had the only object sought been the production of a cherry that ripened very early, it would not have been very difficult to attain success.

In that case all other qualities could have been disregarded, and attention given solely and exclusively to the question of time of fruitage. The cherries that ripen earliest each season being selected, presently a race of early bearers would have been produced beyond peradventure. Selection carried through a comparatively small number of generations would have sufficed to give me what was sought.

But a moment's reflection makes it clear that there would be no commercial value in a cherry that ripened earlier than its fellows, unless this cherry combined with the quality of early ripening other qualities of size and abundance and fitness for shipping that give the cherry its value as a market fruit. It is obvious that in selecting these cherries it was constantly necessary to bear in mind not merely one quality but several qualities, and it requires no great knowledge of plant experimentation to see that this greatly complicated the problem.

Diversified Qualities Required

In point of fact, the qualities that are required in a really satisfactory commercial fruit are much more diversified than the ordinary observer would ever suspect.

In the case of the cherry there are at least a dozen quite distinct qualities, which might be spoken of as unit characters, that must constantly be borne in mind.

A cherry that will bring a good price in the market must be large in size; it must be attractive in color; it must be sweet and savory to the taste; and it is of prime importance, particularly from the California standpoint, that the fruit shall be of such texture and quality of skin as to

bear shipment across the continent, and so reach the Eastern market in good condition.

As much as this will be obvious to every eater of cherries.

But from the standpoint of the fruit grower, there are many other qualities that are no less important. It is necessary that the tree that bears the cherries shall be hardy and able to withstand ordinary frosts; that it shall have the quality of vitality that makes it fairly immune to the attacks of insects; that it shall have abundant foliage to protect the fruit from the sun and birds; and that it shall be a prolific bearer no less than a bearer of fruit of marketable quality.

All this, and more, in addition to the quality of earliness of bearing to which reference has already been made.

If we add that there are certain minor qualities to be borne in mind, such as the question of length of stem, number of cherries to the cluster, and tendency of the fruit to cling to the stone in one case or leave it readily in another, an inkling will be gained of the complications of the problem in heredity that confronts the developer of an improved race of cherries.

But the full significance of these complications can scarcely be appreciated wholly by anyone

who has not been confronted by them in actual practice.

If I have been able to overcome them in a relatively brief number of years, it is because I have worked persistently, selected with discrimination, and invoked the aid of the bees in making experiments on a large scale.

The modern student of heredity, in dealing with cases such as this, is able to give a somewhat tangible illustration of the difficulties involved with the aid of simple mathematics. He does this on the basis of the Mendelian interpretation of the method of transmission of unit characters of which we have learned something in an earlier chapter.

The Complications Illustrated

It will be recalled that we had occasion to consider such opposing traits as blackness and whiteness in our white blackberry, large size and dwarf size in the case of our walnut trees, stone fruit versus stoneless fruit in cases of our plums, and perfume versus lack of perfume in cases of the calla, as pairs of unit characters that are mutually exclusive in case of any individual, but which both tend to recur in the second generation of hybrid offspring.

It will be recalled, too, that a specific illustration of the formula according to which such recurrence takes place, was found in Professor Castle's experiments in crossing a black guinea pig with a white one; in which case, although all the offspring were black, the quality of whiteness reappeared in one-fourth of the descendants of the second filial generation.

Now it should be observed that this ratio of one in four is a ratio that has been found to hold good in a very great number of experiments applied to various races of animals and plants, when a cross has been made and a record kept of the results with reference to a single pair of unit characters, such as blackness versus whiteness in the case of the guinea pigs. In such a case, where the offspring of the second filial generation are interbred, it has been clearly demonstrated that, on the average, one-fourth of the offspring of the second filial generation will resemble the paternal grandparent, and one-fourth the maternal grandparent; the remaining half being of mixed heredity.

Stated otherwise, there is an even chance that in any group of four offspring of the second filial generation, one individual will resemble each

grandparent as regards a single given unit character.

Applying this rule to the case of our cherries, and considering for the moment only the matter of early-bearing versus late-bearing, it should result, if these qualities constitute a pair of unit characters, that by crossing an early-fruiting cherry with a late-fruiting one, the descendants of the second generation would show one specimen in four growing early fruit, one in four growing late fruit, and two of intermediate tendencies.

All that would then be required would be to breed exclusively from the one-fourth that were early bearers, destroying the three-fourths that lacked this quality or had it mixed with the undesirable quality.

Not so Simple in Actual Work

But, unfortunately, the simplicity of the formula vanishes as soon as we come to consider a second, and third, and fourth pair of unit characters.

Here also the formula has been worked out in mathematical terms; and it appears that when several characters are involved, we at once come to deal with numbers that are no longer easy to keep track of. Moreover, the various pairs

of unit characters may be juggled in an almost infinite variety of ways.

We are seeking, for example, (1) an early-bearing cherry of (2) good size, (3) fine color, (4) sweet taste, and (5) good keeping quality.

Suppose, for the sake of argument, we consider each of these to constitute, as contrasted with the opposite condition, one member of a pair of unit characters.

Then it appears that, according to the theory of chances which underlies the interpretation of the Mendelian formula, the probability that any given combination of these five qualities will appear in an individual specimen of the progeny of the hybrid generation is only one in about five hundred.

We shall have early bearers that are of good size and taste, but lack shipping quality; other early bearers that are good shippers but lack size or quality; yet other specimens that have size and taste and shipping quality, but lack the quality of early bearing; and so on throughout all the possible combinations of five pairs of qualities.

But the combination of all the desired characters in a single individual will take place *very rarely indeed.*

And when we advance from five pairs of unit characters to ten or twelve, as we have already seen that we must do in the case of our cherry, the matter becomes almost infinitely complex. As we increase the number of qualities under consideration, the number of possible combinations among them increases at an alarming geometrical ratio.

It appears that whereas there is an even chance, when only a single pair of qualities was in question, of producing one offspring like each parent in each group of four; and whereas there is the same even chance of producing one offspring like each parent in every group of 256 individuals when four pairs of unit characters are in question—when we have to deal with ten pairs of unit characters the possible arrangements have become so bewildering and complex that there is even chance of producing a single offspring like each grandparent only in each group of *more than a million progeny!*

Quantity Production Necessary

Such a computation, as made in accordance with the Mendelian formula, in itself serves to supply a ready answer to those Mendelians who have questioned the necessity of making experiments on the elaborate scale that I have all along

followed out. According to strict Mendelian reasoning, it is clear that we must deal with thousands of seedlings in order to stand a chance of securing a single one that shows a desired combination of qualities, when six or eight qualities are in question—and I seldom work with less than twice this number in view.

And the case is even more complex than this computation would show, because I am always concerned not merely to combine a half dozen or a dozen desirable qualities, but to have a wide range of choice among numerous individuals showing this combination, that one may be found which exhibits the desired qualities in the *superlative degree.*

It is fair to assume, then, that I should never have secured the Burbank Cherry, and following it my newer varieties of cherries that: (1) fruit weeks before the usual cherry season, and (2) produce a superabundant crop of fruit of (3) the largest size, (4) best color, (5) firmest texture, and (6) finest quality; growing in (7) easily gathered clusters on (8) trees of fine shape that are (9) hardy and (10) immune to the attacks of insects, had I not extended my experiments far beyond the narrow limits of hand pollination, with the aid of my hosts of indispensable helpers, the bees.

THE ABUNDANCE CHERRY

This shows the actual size and appearance of one of my cherries called the "Abundance." Like the "Giant," it is the product of crossing between the various highly developed members of the cherry colony. I do not introduce a new fruit unless it is equal to any existing variety in all its qualities, and superior to any other in at least one quality. The "Abundance" Cherry fully meets these conditions, its pre-eminent quality being its habit of early and prolific bearing. In size it is also notable, as the illustration shows.

So the biometric computations give fullest support to the practical methods that I have employed for the past fifty years.

Meantime, the results of these experiments—proving the possibility of segregation and reassembly of these diverse qualities — give vivid illustrations of the fundamental truth of the theory of unit characters, *if these be properly interpreted.*

Good Fruit from Bad Ancestors

As a further illustration in point, note this curious circumstance:

I have in various instances used as a parental stock, for purposes of hybridization, a cherry that produced a totally worthless fruit. The object of this selection was to introduce into a developing strain of cherries some good quality — say prolific bearing — that the otherwise worthless cherry exhibited in high degree.

The immediate progeny of this cross would be of no value as the bad qualities of the worthless cherry were dominant. But among the remoter descendants I have been able to discover individuals that combine the quality of prolific bearing with the good qualities of the other parent stock, and in which the undesirable qual-

ities of the original worthless ancestor were quite eliminated.

It must be clear that this result could not have been brought about if the various pairs of qualities—large size versus small size, sweetness versus sourness, prolific versus shy bearing, and the like—had not been separated in the germ plasm of the hybrids in such a way that the unit characters could be sorted out and any good quality transmitted unimpaired by its contact with the opposing bad quality.

In other words, had there been a blending of traits in the sense in which the older experimenters imagined the traits of hybrids to be blended, we should have had at best a cross in which the qualities of the worthless cherry were mingled with those of the valuable one; a race which, if better than its worthless ancestor, was worse than its valued one.

And it might never have been possible to breed out altogether the undesirable qualities that the original cross had introduced.

Separating the Traits

But we have seen in the case of the cherries, as we had previously seen in the case of some other plants, and as we shall have occasion to see in numberless others in future, that it is possible

to breed traits into a hybrid strain, and then breed them out again.

In point of fact, no progress in the production of new varieties could have been made in my experiments, were it not for this possibility.

The Shasta daisy, for example, is not intermediate in size between the species from which it sprang, but larger than any of them. The white blackberry is not intermediate in color between the parental strains, but is of a far purer white than its light-colored ancestor. The stoneless plum is more stoneless than the race from which it sprang, although that race has been crossed again and again with strains of plums that invariably produce a stony seed covering. Some of my hybrid walnuts are far larger than either parent stock, and some are far smaller than either.

And so on throughout the list of the hybridizing experiments through which the new races of plants have been developed at Santa Rosa. Everywhere we find evidence of segregation of unit characters and recommingling and reassortment in later generations.

Nowhere else, probably, can there be found such an aggregate mass of testimony to the operation of this principle as will be supplied in the pages that tell of my various experiments.

And, reverting to the cases in hand, there is no better illustration of the truth of this proposition than that furnished by the new cherries which present, in a single individual, ten or a dozen clearly definable qualities that have been sorted out and brought together from the commingling of widely divergent ancestral strains.

The traits that were developed through response to the environment in widely scattered geographical territories and through hundreds of generations, have been brought together, in combinations never hitherto presented; with the result that my early-bearing, large-sized, bright-colored, and highly flavored cherries constitute essentially a new variety of fruit, while at the same time they evidence with full force the all-compassing influence of the laws of heredity.

According to strict Mendelian reasoning, it is clear that we must deal with thousands of seedlings in order to stand a chance of securing a single one that shows a desired combination of qualities, when six or eight qualities are in question—and I seldom work with less in view.

THE SUGAR PRUNE

How a Tree Was Changed to Fit the Weather

PROBABLY you have heard the story of the general who declared it impossible to build a bridge across a certain stream that obstructed the march of his army until he had plans and specifications and blue prints for the work. While he waited for these—so the story goes—a subordinate built the bridge, and reported to his superior with the suggestion that it might be well to march the men across the bridge forthwith and then make the drawings at leisure afterward.

A visitor at my orchard told me this story, and applied it to the case of some of my newest varieties of plums.

"It appears to me," he said, "that your custom resembles that of the young soldier who built the bridge without the plans and specifications. You appear to have developed a good many of your fruits on the same principle. You seem to have

gone ahead and produced the fruit, while a more cautious experimenter would have been occupied in designing hybridizing methods and testing unit characters, and would not have been fully prepared to start on the actual constructive work until about the time you finished."

Whatever the force of this comparison, it is true that I have often succeeded in producing a fruit of the finest quality by methods that to a less practiced experimenter might look haphazard; methods that did in point of fact lack something of the precision that an investigation conducted solely for purposes of scientific record rather than for practical results might have required.

Such is the case with a large number of experiments in plum breeding. Here I have dealt with such vast numbers of individuals and brought into the hybridizing tests such varied and so many races, that accurate record of every step of a series of experiments extending over a term of years was quite out of the question.

My "Combination" plum has a pedigree that includes strains of almost every race of plums under cultivation.

From the seed of this strange hybrid you may produce trees that will bear fruit closely similar in all respects to at least a score of entirely

different well-known varieties or races of plums. The mixed pedigree of the product is recorded in this motley galaxy of offspring; but details as to all the parental crosses, tracing back along an experimental search of thirty years' duration, are not to be had. The original parents used in the first cross are of course known; but successive generations deal with tens of thousands of seedlings. So it was impossible for anyone who was carrying out, as I have been, not less than three thousand different plant-breeding experiments each year, involving in the aggregate not fewer than six thousand different species, to trace accurately, much less to record, each and every cross-fertilization among the myriad blossoms of my orchard.

Yet a chance hybridization might by some good fortune effect precisely the needed combination of qualities to produce a fruit that had long eluded my most earnest efforts at systematic breeding.

But by my very extensive and varied experience I can judge from the result what the racial strains most probably were that were blended to produce the new hybrid. But even this is not always possible, and not a few among the thousands of new varieties of plums that have originated on my farms are of untraced and untrace-

able pedigree, at least as regards some of their strains.

When I say that something like seven and a half million seedlings of the plum have passed under my hand and eye in the course of my many series of experiments in the perfection of this fruit, the reader will not wonder that there are gaps in the record, otherwise there would be only records not plums.

Difficulties Involved

On the other hand, it must be understood that there are almost numberless instances in which the hybridizing of different strains of plums has been effected by hand, in accordance with the most rigid scientific methods, and accurately recorded in my plan books. Indeed, this is true in almost all cases of the first cross through which a tendency to variation has been brought about.

The first generation hybrids are usually very much alike, and inspection of them often gives no clues to the ultimate results to be expected. But in the next generation all the divergent characteristics of both racial strains strive for representation, and the diversity of forms produced may baffle anything like accurate description.

Beyond this stage it is usually necessary for the practical breeder to turn over the task of

cross-fertilization to the bees, contenting himself with keeping a sharp outlook for seedlings that show desired combinations of traits.

How diversified these traits may be in case of a market fruit has been illustrated at some length in the preceding chapter. In this respect, most plums are at least as complex as the cherry, and the requirements in the case of the "perfect" prune are even more exacting.

The word prune, it should perhaps be explained, is applied in California to any plum that can be dried with the stone in place without fermentation of the pulp. The quality that permits such drying is largely dependent on the amount of sugar that the fruit contains. There are prunes and prunes, as even the most unpracticed observer must know, and there are gradations of size, flavor, and sugar content that are vastly important from the standpoint of the orchardist and by no means without interest from the standpoint of the consumer.

One of the tasks I early set myself was to produce a prune that should excel all others in the qualities, singly and combined, that make for perfection in this valuable fruit, and there can now be no doubt but that this end is fully accomplished, although I shall not say that my complete ideal of a perfect prune has thus far been

quite attained. I am not sure that I should be overpleased if it had been; one does not really wish to reach the end of a trail, leaving nothing to strive for, no unknown territory to explore.

It is a matter of record that the prune was originally introduced into California by a French sailor named Louis Pellier, who came to San Francisco in 1849 with the first horde of gold seekers.

Prunes from France

Failing to make his fortune in the mines, this young man, in association with his brother who had presently joined him, established a nursery and conducted it with a certain measure of success until 1856 when one of the brothers returned to France to bring back a bride. He brought also some prune cuttings. And these, notwithstanding the long journey by way of the Isthmus, were still alive when California was reached.

They were immediately grafted upon plum stock, with entire success.

The most important of the varieties of prune thus introduced was the common French prune, sometimes known as the prune d'Agen. The descendants of this stock made up the large prune orchards of California for the ensuing half century.

The French prune, while not without its good points, is by no means a perfect fruit. It is a clingstone, which is a serious defect in a prune. Moreover, the stone itself is rather large in proportion to the flesh. The fruit ripens too late to be profitable in some parts of the country, and the risk of having the crop destroyed by the early rains is a serious defect everywhere. Neither is the tree a strong grower, or a very reliable producer, or of the most symmetrical growth.

It occurred to me, therefore, when I first took the matter in hand, that among the essential qualifications of the ideal prune at which I must aim would be early ripening and the production of a larger, still sweeter freestone fruit that would be borne in profusion.

The Ideal Prune

We have had occasion to point out that the common orchard fruits do not breed true when grown from the seed. Explanations of this fact have been given, and fuller explanations will appear in subsequent chapters.

Here it suffices to note that the prune is no exception to the rule.

Very seldom does the seed of a prune tree produce a fruit that much resembles the prune.

THE SUGAR PRUNE AND ITS PARENTS

The Sugar Prune was developed by selection from a cross between the French prune and the Hungarian prune. From the former it inherited sweetness and flavor and from the latter size. It improved on each parent, however, manifesting, also, a most unusual vigor. The French prune is still largely grown in California, but this and others of its improved descendants must ultimately displace it.

Usually the fruits are of all sizes, shapes, and colors. They are sweet, sour, bitter, as the case may be. Some of them crack and others remain smooth. The trees on which they grow are many of them ill-shaped, weakly, or subject to disease. Although the parent form may have been an early ripener, the seedling may produce fruit that ripens so late as to be useless.

All of which serves to give an inkling of the difficulties that beset the plant experimenter who sets out in pursuit of an ideal prune.

Moreover, the variety of characteristics required to make up the ideal prune is far greater than the novice might suppose. It is a matter of course that the fruit should be large and well flavored—though not too large, lest it become too difficult to dry; and that it should be produced in abundance.

But there are various equally essential points that the novice might overlook.

There is, for example, the matter of quality of skin, determining the fitness of the fruit to undergo the lye bath which is an essential part of prune curing.

It is necessary to dip the prunes in this bath, consisting of a solution of potash or lye, in order that the skin may crack in such a way as to permit the rapid evaporation essential to quick dry-

ing. But, in a very large number of cases, prunes that have every other essential quality fail when subjected to this final test. It is not too much to say that I have developed hundreds of new varieties of prunes that were well nigh perfect as to quality, but which had no commercial value whatever because they failed to stand the acid—or to be literal the alkali—test.

So the experimenter is always confronted with the possibility of failure at the very last, even when his efforts seem to have met with complete success at the earlier stages. With the utmost solicitude, therefore, he must watch the fruit as it passes through the potash bath.

If the skin peels from the fruit instead of cracking, that particular variety is worthless, no matter what its other good qualities.

Moreover, the cracks in the skin must be very small and numerous. If they are too far apart by the hundredth of an inch the prune will have a rough appearance that mars it from the commercial standpoint. If the skin is too thin, so that in gathering and handling the fruit is bruised, it can never make a commercial prune. But, on the other hand, the skin must not be too thick as then it would not be properly cut by the lye. In a word, there must be the most nicely balanced qualities of the skin of the fruit, and

without this final touch the prune is a failure, even though it grows to seeming perfection on the tree.

The intrinsic qualities, in addition to perfection of skin, that I aimed at from the outset, were large size, increased production of sugar, and early ripening.

The matter of size is doubly important because this largely determines the price that a prune brings in the market. The sugar content is obviously important because upon this chiefly depends the drying quality of the fruit. And the matter of early ripening is at least as essential as any other quality, because the prune is dried in the sun, and the fruit that ripens late in the season not only often lacks sunshine to complete the process, but may be absolutely ruined by the rains which begin to fall in the early autumn.

How I Achieved Success

When I began the quest of a perfect prune, in the year 1879, it at once occurred to me that something might be accomplished by hybridizing the French prune with another variety known as the English Pond's seedling but usually called in California the Hungarian prune. This was a large and handsome fruit, while the French prune brought to the combination the qualities of

rich flavor and relatively high sugar production. If these diverse qualities could be combined in a single fruit, I saw that a great advance would be made.

The little French prune was selected as the mother tree and many thousand blossoms were hand-pollinated from the Hungarian.

The offspring of this cross were as variable as had been expected, and among the seedlings were some that produced fruit of superior quality. Four years later, at the meeting of the California State Horticultural Society, I had the pleasure of exhibiting no fewer than seventy varieties of the most promising of these crossbred seedlings. And in 1893 two new plums were introduced as representing the best selection among the almost myriad forms of the hybrid progeny.

One of these new plums was named the Giant, the other the Splendor.

The former is a handsome plum practically intermediate in qualities between the original parents. It has peculiar value as a shipping plum, and in particular it gained popularity with the canners because its skin has the property of rolling away from the fruit when placed in boiling water, leaving the rich, honey-colored flesh. But these, of course, are not the qualities desired in the prune.

The other variety, named the Splendor, is about one-third larger than the common French prune and contains something like 5 per cent more sugar; its quality and flavor are also superior. It has, moreover, the drying qualities of the prune, and it was freely predicted by many who knew it that it would soon completely displace its French progenitor.

But unfortunately it had one single peculiarity that placed it at a disadvantage; namely, the propensity of the fruit to cling to the tree when ripe.

It dries into a first-class sweet prune, but it dries on the tree, and that is an insuperable defect, because the prune grower demands that the fruit shall fall naturally to the ground. He does not wish to be obliged to take the trouble even to shake the tree.

So the unfortunate propensity of the new prune to hold to its moorings, so to speak, greatly marred its value.

At Last a Superlative Prune

In the year 1899, however, after almost twenty years of continuous and laborious effort, I was finally able to present a prune which met the expectations of the most sanguine; a prune which combined all the good qualities of its progenitors

and combined them in superlative degree, and which, in addition, had the peculiarly desirable quality of ripening about the first of August, two or more weeks in advance of the usual period of the prune harvest.

This almost perfect prune was placed on the market in 1899 under the name of the Sugar Prune.

A description of the new fruit was given by Mr. B. M. Le Long, secretary of the California State Board of Horticulture, as follows:

"The Sugar prune is an extremely early prune, ripening August 1; it grows superbly with yellow flesh, tender, and rich in sugar. The skin is very delicate, at first of a light purple tinted with green, changing at maturity to dark purple, covered with a thick white bloom. The form is ovoid, slightly flattened, measuring five by six and a half inches in circumference, average size fifteen to a pound, which is two or three times larger than the French prune; the fruit stalk is short, and severs very easily from the stem as the fruit reaches maturity; the pit is of medium size, flattened, slightly wrinkled and most often separated from the flesh; the skin is so thin or porous that the fruit begins to shrink on the tree as soon as ripe."

To add to the value of the Sugar prune, the tree on which it grows is unusually vigorous and astoundingly productive; in fact, almost to a fault.

Analysis of the fresh fruit at the State University discloses the fact that it is nearly one-fourth sugar—the exact amount being 23.92 per cent, contrasted with the 18.53 per cent sugar content of the French prune, and the 15.33 per cent of prunes in general.

Not only does the Sugar prune contain far more sugar than any of the varieties from which it sprang, but it fully equals the French prune in flavor, and it is two to three times as large. It is far more productive, and can be grown for one-third to one-half the cost of producing the French prune. In flavor it is fully equal to the celebrated Imperial, and, in most striking contrast to that fruit, it is exceedingly productive.

Add that the new prune excels all other varieties in the extreme earliness of its time of fruiting, and it will be obvious that the Sugar prune marks at least a long step toward the ideal at which I aimed. It ripens at a time when the weather is hot and dry, so that it can be rapidly cured. A week or two later when the other varieties are maturing, the weather is often foggy and cloudy and sometimes even rainy, so that fruit

curing is carried on under difficulties and often with serious loss.

It is not strange, then, that the Sugar prune met with an immediate and enthusiastic welcome from many fruit growers, although of course there were regions in which a prejudice was shown against it, such as always meets any new product.

In the markets of the East, the demand for the Sugar prune was soon far in excess of the supply.

A Wonderful Laboratory

We have seen that the essential quality of the prune, and that which differentiates it from plums in general, is its inherent tendency to produce a large percentage of sugar.

A great number of fruits share with the prune the capacity to manufacture sugar, but few other fruits have the power in such supreme degree. The manufacture of sugar by fruits is so familiar a phenomenon that we usually take it for granted and give it no thought. Yet a moment's consideration makes it clear that this capacity is one of the most extraordinary functions in the whole list of vital phenomena.

Holding a ripe prune in my hand I am sometimes led to reflect that this is in many ways the most remarkable of chemical laboratories.

Within the cellular structure of this fruit a combination and metamorphosis of chemical products is brought about that the most skillful of human chemists is unable to duplicate. Every chlorophyll-bearing plant, to be sure, possesses in greater or less measure the capacity to manufacture sugar and starch and to transform these substances in either direction. But the fact that this attribute is characteristic of plants in general does not make it the less mysterious for the thoughtful observer.

The chemist is able to analyze starch, and he tells us that it is a compound each molecule of which contains six atoms of carbon, ten atoms of hydrogen, and five of oxygen.

But, while he makes his analysis and determines the proportions of the component elements, he is careful to assure us that these elements are doubtless associated in very complex combinations of which his analysis gives him only a vague inkling.

If we glance at the formula by which the chemist represents a molecule of starch—$C_6H_{10}O_5$—the thought at once suggests itself that this seems to be a union of six atoms of carbon with five molecules of water; for of course we are all familiar with the formula H_2O as representing water, however little we may know of the other niceties of chemistry.

A LUSCIOUS FRUIT

This shows a specimen of the "Standard" Prune. (Enlarged one-fourth.) This prune is so large that nine or ten of them weigh a pound. The stone is so relatively small that it represents only three-fifths per cent of the total bulk. It is also freestone — a very great merit, as every user of prunes will admit. These massive prunes are often sold in the market as plums to be eaten fresh.

And in point of fact, this is about the way in which the chemist regards the matter.

Starch is a compound of water and carbon. The plant secures the water from the soil and the carbon from the atmosphere, where it exists in the form of carbonic acid gas, which is given out constantly from the lungs of every living animal.

With these simple and universally present materials, then, the wonderful chemist of the plant laboratory builds up the intricate substance through glucose and levulose into what we term starch.

This substance is stored away in the plant cells, not for the moment available for the purpose of nutrition, but constituting a reserve store of food material upon which the tissues of the plant can draw at need.

Starch itself when stored is insoluble in the juice of the plant, but to make it available whenever needed it is only necessary for the plant chemist to add to the compound the constituents of a molecule of water, namely two atoms of hydrogen and one of oxygen, and the starch is transformed into a soluble sugar called glucose or levulose.

This substance, again dissolved in the juice of the plant, may then be transferred to the place

where it is needed; which, in the case under consideration is the kernel of the fruit.

The process of sugar manufacture with the final storing of the sweet product in the flesh of the prune, constitutes, as I have just suggested, one of the most marvelous manifestations of the power of vegetable cells. Indeed, it is precisely this capacity that differentiates vegetable tissues from all animal tissues whatever; for the biologists tell us that no living organism, high or low, save only the vegetable, is capable of manufacturing a single molecule of starch, much less a molecule of sugar out of inorganic materials.

So a thoughtful person can scarcely fail to regard even so plebeian a thing as a prune with a certain measure of wonderment, almost of awe, if he allows himself to reflect on the mysterious processes that have taken place within its structure.

The Elements of Variation

From the present standpoint, however, we are not so much concerned with the mysteries of plant chemistry as with the extremely practical fact that the new Sugar prune developed in my orchard has the fixed habit of setting its sugar-making laboratory in operation several weeks earlier than had been the custom with the ancestral races of prunes.

This interesting and important change of habit had been brought about, as the reader who has perused the earlier chapters will surmise, by a process of selecting, generation after generation, the individual prunes that manifested a tendency to early fruiting. But here as elsewhere we are confronted with the question as to how it was possible thus to change so markedly the habits of a plant within a few generations.

The answer carries us back, in imagination, along lines we have followed in studying other plant histories, to the remote ancestors of the sugar prune.

We are led to reflect that the time of fruiting of a given plant is largely dependent upon the climate in which the plant habitually grows. Now there must have been ancestors of the prune that grew far to the north, for the plum is a hardy plant. Among some of the remote and now untraceable ancestral strains there were doubtless some that produced their fruit at least as early as the first of August, perhaps even earlier.

And although (when interbreeding occurred) the hereditary tendency to early fruiting had been made subordinate to the late-fruiting tendencies of other races of plums that had grown in milder climates, yet the potentialities of early fruiting were never altogether lost.

Hence among the multitude of seedlings that were produced by these hybridizing experiments, this trait, along with a multitude of other submerged ancestral traits, was now able to make itself manifest. And it was my task, by a process of selection, to make sure that the character was preserved.

The matter is perhaps made a little clearer if we reflect that in any race of domestic plants there is a considerable range of variation as to size of fruit, abundance of bearing, and time of fruitage. Such variations represent, as we have pointed out, the varying traits of diverse strains of ancestors. But it must be observed that there are always somewhat clearly defined limits beyond which variation does not readily go.

Among all the thousands of types of prunes grown on the seedlings of my hybrid colony or on the grafts on some receptive tree, there will be individual fruits varying, let us say, from one-half inch in length to perhaps two and a half inches—but apparently there will not be a fruit six inches in length.

Similarly among these seedlings there will be some that ripen their fruit as early as the first of July, but none that ripen so early as the first of May.

Fruits of other species may ripen far earlier; the cherry does so quite often. But the ancestors of the plum have sometimes lived under conditions that made it necessary for them to mature their fruit much before midsummer. So their range of habit in this regard, as recorded in the stored hereditary tendencies, was limited. And the possibilities of variation among these hybrid seedlings are correspondingly limited, because, as has hitherto been pointed out, heredity is but the symbol of the sum of past environments, and the hereditary limitations of any common race of plants to-day are somewhat restricted by the aggregate limitations of all their ancestors.

Reversion to the Average

Such an analysis, in which the varying conditions that environ the different strains of a hybrid's ancestry are kept constantly in mind, serves to give us a clue to the observed tendency of families or strains of animals or plants to revert in successive generations toward a given mean or average.

It has long been observed that, as a general rule, the offspring of human parents that are exceptionally tall tend to be shorter than their parents; whereas, contrariwise, the offspring of dwarfs tend to be taller than their parents.

In studying races of animals and plants, biologists have discovered that this tendency, spoken of as tendency to revert to a mean, is universal.

The matter has been especially studied in recent years by the Danish biologist, Professor W. L. Johannsen, of Copenhagen. His studies of barley and of kidney beans show that any given race of these plants is really made up of a number of subordinate races, representing different strains of the ancestral pedigree, and that when the plants are self-fertilized, the progeny tend to group themselves into a few more or less permanent types.

There are limits of variation as to size, color and qualities, but the progeny as a whole do not tend to have offspring that approach the halfway mark between these two extremes. Rather they break up into groups, each group tending to reproduce itself in such a way as to form a new subordinate race or "pure type." Thus from the same mixed stock sundry races of relative giants and of relative dwarfs, as well as numerous intermediate races, are formed.

Now it would appear that such a case as that of the prune, in which we are able to work out by artificial selection a race characterized by tendency to early fruitage, is in keeping with these studies of the so-called "pure lines" of de-

scent to which Professor Johannsen has given special attention.

But it must be understood that it is exceedingly difficult to carry the experiment in the case of the prune to the stage at which the type becomes absolutely fixed, for the reason that there are so many other qualities to be considered.

This matter of varying qualities represented in the same seed we have discussed before, and we shall have occasion to refer to it again and again. Here it suffices to note that the case of the prune is akin to others that we have examined, for example the hybrid walnuts and the early cherries, in that the qualities for which we have bred are so numerous and so varied that they can be aggregated only in one seedling among many thousands, and could not be fixed without a long series of generations of additional breeding.

Fortunately this is of no practical consequence because the prune, like other orchard fruits, may best be propagated by grafting. From a single seedling we may thus develop, in a short time, an entire orchard or a series of orchards.

Such is in practice the method of propagating the sugar prune. It is obvious that plants thus grown partake of the very substance of the original seedling; they are part and parcel of it,

and fruit grown from such grafts will be uniform in quality, within the limits of variation that characterize the individual specimens of any fixed race.

> *When I say that something like seven and a half million hybrid seedlings of the plum have passed under my hand and eye in the course of my many series of experiments in the perfection of this fruit, the reader will have little wonder that each individual cross has not been recorded; though all of practical importance have been.*

SOME INTERESTING FAILURES

A Petunia with the Tobacco Habit—And Others

A WELL-KNOWN critic, after a visit to Santa Rosa, commented on my work in a way that seemed to suggest that what most appealed to him was the great variety of experiments constantly being carried on.

"Every plant seems to appeal to Luther Burbank," he said. "This appeal is quite like the appeal that is made to the botanist but not to the horticulturist; Burbank likes it because it is a plant and because he would like to modify it for human use. Therefore he grows everything he can, no matter where it comes from or of what kind. He cultivates with personal care, multiplies the stock to the limit of his capacities, scrutinizes every variation, hybridizes widely, saves the seeds of the forms that most appeal to him, sows again, hybridizes and selects again, uproots by the hundreds and thousands, extracts the delights from every new experience, and now

and then saves out a form that he thinks to be worth introducing to the world.

"Every part of the work is worth while of itself; at every stage the satisfaction of it is reason enough for making and continuing the effort. Every form is interesting, whether it is new or the reproduction of an old form. He shows you the odd and intermediate and reversionary forms as well as those that promise to be of general use.

"All this leads me to say that the value of Mr. Burbank's work lies above all merely economic considerations. He is a master worker in making plants to vary. Plants are plastic material in his hands. He is demonstrating what can be done. He is setting new ideals and novel problems.

"Heretofore, gardeners and other horticulturists have grown plants because they are useful or beautiful; Mr. Burbank grows them because he can make them take on valuable and beautiful new forms. This is a new kind of pleasure to be got from gardening, a new and captivating purpose in plant growing. It is a new reason for associating with plants. Usually I think of him as a plant lover rather than plant breeder. It is of little consequence to me whether he produces good commercial varieties or not. He has a sphere of his own, and one that should appeal

to a universal constituency. In this way Luther Burbank's work is a contribution to the satisfaction of living, and is beyond all price."

Such, in a way, appreciative though sometimes thoughtless notices of one's work are of course more or less agreeable, and I am bound to admit that what is said about my love of experimenting with any and every kind of plant is altogether true.

There is one point, however, at which I am forced to part company with the commentator. To me it *is* a matter of vital consequence as to whether I "produce good commercial varieties or not." It is necessary that I produce valuable, useful varieties, inasmuch as I have all along paid all my heavy expenses by the sale of my products which could never have been the case if they were not improvements on all those previously grown. I have produced hundreds of priceless varieties which have received universal recognition over the whole earth.

Had I not produced good commercial varieties my practical success would have been something very different from what it has been.

Profession without possession will do for a time, but the "goods" must be forthcoming for permanent success.

Nevertheless, it is of course true that the successful commercial varieties of plants and fruits are comparatively few in number as contrasted with the vast numbers of forms with which I have experimented. It could not well be otherwise, for it would be a strange and novel form of experiment that led always to success. But of course the public in general hears of, and in the main cares for, successes only. There is seldom any reason for exploiting a failure. And so a long list of experiments that have led to no practical result has scarcely been heard of by the public in general.

Some of these, however, are in themselves highly interesting, and I have thought it worth while to take the reader into my confidence to the extent of telling about three or four series of experiments which produced no permanent new forms of flower or fruit, and which from the commercial standpoint resulted only in loss of time and money.

There are certain lessons to be drawn from these that I think will command the reader's attention and interest.

A Misguided Petunia

One of the most unusual hybridizing experiments that I have performed consisted of cross-

ing the common garden petunia with a variety of tobacco known as *Nicotiana Wigandioides rubra.* In this cross the petunia pollen was used to fertilize the pistil of the tobacco plant. The seed thus produced was planted in the summer, as soon as it ripened, and possibly two hundred plants were raised.

When about a foot high the plants were placed in boxes in the greenhouse to keep over winter. They revealed no inclination to bloom, nor did they vary greatly from the parent tobacco plant, except in the matter of growth, which was very uneven, some of the hybrids being two or three times as large as others, and several were inclined to trail. The foliage was somewhat unusual; yet its resemblance to the tobacco was so great though smaller that a casual observer would have doubted whether the cross had really been made.

In a word, the characteristics of the tobacco plant seemed to preponderate.

But toward spring, when the plants were again placed out of doors, they soon began to show the influence of their mixed heritage. Some of them turned crimson, and others pink; yet others remaining green. Moreover, the plants themselves developed a great diversity of habit. Even during the winter some of them had begun to fall over and show a tendency to trail like vines.

As the season advanced, some of these became genuine trailers like the petunia, and produced blossoms altogether different in color from the red flowers of the tobacco plant.

These plants did not bloom very abundantly, but their great diversity of form and peculiarity of foliage and flower made them a very striking lot of plants.

Some of them grew four or more feet in height with large tobaccolike leaves, and others were trailing dwarfs that to all appearances might have belonged to an entirely distinct race.

The plants that closely resembled the tobacco parent were, for the most part, weeded out. The ones that gave evidence of their hybrid origin were carefully nurtured. But it was noticed toward fall that although the tops grew splendidly, there seemed to be an unusual lack of roots. The plants would come to a certain size, and then take on what could perhaps be best described as a "pinched" appearance, from lack of vitality incident to their defective roots. There was, however, a great difference among the individual plants, some of them remaining strong throughout the season.

When the plants were taken up, it appeared that the sickly ones had produced only a few frail, wiry roots. It appeared to have been

impossible for them to develop a thoroughly good root system. Evidently many of the new plants had inherited the rank-growing tops of the giant tobacco and the smaller, less efficient roots of the petunia.

A visitor whose attention was called to this peculiarity remarked facetiously that my petunias had obviously been stunted in growth and vitality through acquiring the tobacco habit, just as boys are stunted when they make the same mistake. It is only fair to recall, however, that the petunias had no choice in the matter. Their association with the tobacco had been thrust upon them.

Owing to the lack of vitality of the hybrids, and the fact that they seemed unlikely to develop additional characteristics of exceptional interest or to produce seed the plants were not especially sheltered, and they perished from freezing during the ensuing winter. Thus the experiment of hybridizing the petunia and the tobacco came to an end; not, however, without illustrating one or two suggestive points of plant breeding to which further reference will be made in due course.

Some Mongrel Potatoes

Inasmuch as my first experiments in plant breeding had to do with the potato, it is not

strange that the tribe of plants to which this vegetable belongs have always had for me a rather exceptional interest.

Early in the course of my California work I had secured specimens of a remote cousin of the cultivated potato which grows in our southwestern States and which is known to the Indians as the Squaw potato (*Solanum Jamesii*).

It is a wild rambling potato, spreading in all directions by tubers that are connected by long strings. Although used for food by the Indians, this potato is not worth the notice of the cultivator, except for its hardiness. This trait suggested that it might possibly be crossed to advantage with other species. But although several crosses were effected with three other species of the potato, nothing of value came of them.

An allied species, however, namely the *Solanum Commersoni,* a worthless form introduced from central South America, gave more interesting results.

This plant, although recommended as a valuable commercial product, really had very little value. Like most wild potatoes, it scattered its tubers widely from the hill; moreover it had an ineradicable bitter taste that made it unpalatable. The blossoms, however, were very large and

handsome and, unlike the blossoms of the ordinary potato, they were quite fragrant.

Moreover, the blossoms were produced in astounding profusion. But the plants did not ordinarily produce seed. When I crossed the plant with other tuberous Solanums, however, a number of seed balls were produced and by cross-fertilization the plants had acquired a virility that they otherwise lacked.

These hybrid seeds produced many strange forms of potato plants. Some had extremely large blossoms in great quantities, others extremely small ones; the blossoms varied in all shades from deep blue through sky blue to red and white. Some of the blossoms might have been thought not unworthy to be introduced as garden ornaments. But they offered no advantage over numerous flowers already in existence, and as the tuber proved worthless, these experiments also were discontinued.

But by far the most interesting experiments that I have made with the wild potatoes were made by combining the form known as the Darwin potato (*Solanum maglia*), a yellow fleshed tuber producing an abundance of very large seed balls, with the common potato, and with various other tuberous Solanums. Thus I produced a plant which yielded balls of fruit at least three

POTATO SEED BALLS

Most of our cultivated potatoes do not ordinarily produce seeds. The fruit resembles a miniature tomato, as this picture will suggest. It was through finding such a seed ball on the Early Rose potato, which never before or since has been known to bear seed, that the well-known "Burbank" potato was developed.

or four times as large as those ever produced by the ordinary potato.

In one case the fruit of this hybrid proved to have a most excellent flavor, in some respects superior in quality to the tomato. It was snow white when ripe, and had also a highly pleasing aroma. The flesh of this fruit resembled that of a firm, very sweet tomato. To the taste it suggested a delightful commingling of acids and sugars.

As the fruit grew on a hybrid potato vine, and in itself had much the appearance of a tomato, it was christened the "Pomato."

The name itself was appropriate enough, but was unfortunate in that it led to the unauthorized assumption that the fruit was really a cross between the tomato and the potato. In point of fact, I have never been able to cross these two plants, and there was no strain of the tomato in the ancestry of the new fruit.

The pomato plant produced fruit abundantly, but very few tubers, and when the latter were planted, the vines seemed to run out, giving their entire attention to the production of seed balls. And the seed when planted never reproduced itself exactly true to form, showing its hybrid quality by the production of unique and abnormal forms.

Thus there was no practical method of propagating the pomato, the tubers being wholly absent or merely rudimentary, and the seed not producing a satisfactory uniform product.

It is probable that if I could have found time to continue the experiments, I should have been able to fix the race through selection, and thus have added a fruit of an altogether new variety to the list of garden products.

But to have done this would have necessitated experiments on a large scale, requiring more time than I could give at the moment.

I think it not unlikely, however, that some one will take up the experiment in future and develop a fruit comparable to my pomato that will have commercial value and be generally cultivated, for there seems to be no reason to doubt that the variety might be fixed with time and patience.

Some Hybrid Berries

One of the most curious hybridizing experiments ever conducted was made in an effort to test the limitations of affinity between the various members of the rose family. I had on my place a bush of the California dewberry (*Rubus vitifolius*), a plant that differs from most other members of the family in that its staminate and pistillate flowers are borne on separate plants.

The particular bush in question had only pistillate flowers, and as it grew in isolation, miles from any similar plant, its flowers were rarely fertilized and ordinarily bore *no fruit*. At most it occasionally developed single drupelets, a result possibly of partial fertilization from grains of pollen accidentally brought from a distance by wind or insect.

The isolation of the plant, and the fact that it bore unisexual flowers, seemed to offer a favorable opportunity for some experiments.

Upon this plant I applied the pollen of various species of plants of the same family. The list is a striking one, for it included the apple, the mountain ash, the hawthorn, the quince, the pear, and various kinds of roses, but no blackberry or raspberry.

I worked at these hybridizations attentively during the blooming season of the dewberry in the summer of 1886.

The pistils thus fertilized developed an abundant crop of fruit, and in the ensuing season I raised from these berries between five and six thousand seedlings.

Never on earth, perhaps, was there seen a more widely varying lot of seedlings that were the immediate offspring of a single plant. The hybrids took every possible form that could be

suggested as combining the traits of the various parent plans. Most of them were absolutely thornless. Many grew upright like the apple tree, showing nothing of the drooping tendency even of the raspberry, much less the trailing habit of the dewberry. The leaves were generally quite smooth, some resembling those of the pear, others being partially trifoliolate, and most of them assuming strange and unusual forms.

When this motley company came to the time of blooming, there was still another surprise, for the flowers were as varied as the foliage. Some of the blossoms were crimson in color, and half as large as an apple blossom; some were pink and quite small; others were white. A large number of plants, however, did not bloom at all, although they were attentively cared for during several years, and were otherwise normal.

From these strange hybrids I thought it barely possible to raise at least one or two remarkable varieties of fruit. I had hopes even of being able to produce something of real value, at any rate from the second generation.

But when it came time for the fruits to ripen, another surprise awaited me; only two plants out of the five thousand produced a single fruit. One of these was a plant somewhat resembling a raspberry bush, and this produced a number

of ill-tasting berries of a yellowish-brown color. The other bush produced insignificant fruits of an orange-yellow color.

Though unpromising in themselves, these fruits were most carefully watched and guarded, for I felt convinced that possibilities of strange variation were contained in them, if only a few seedlings could be produced from them. But when the fruits were fully matured I examined the seeds and found all of them hollow. They were nothing but shells, containing no kernel.

So by no possibility could I get a single seedling for a succeeding generation.

Some of the most curious of the plants were preserved for two or three seasons, but they proved as unproductive as before; and as the ground was needed for other purposes I felt constrained to destroy the entire company of curious hybrids. But in all my experience I never destroyed a lot of plants with more sincere regret.

An experiment perhaps even bolder was made at about the time of this experience with the hybrid dewberries. This was the hybridization of the strawberry and the raspberry.

The attempt to cross plants of such very unlike appearance would seem to most experimenters absurd. Yet the cross was successfully

LEAVES OF STRAWBERRY-RASPBERRY HYBRIDS

The strawberry-raspberry hybrids had leaves which were uniformly trifoliolate, but which varied greatly in size and shape. Characteristic samples of the different forms are here shown. It was peculiarly to be regretted that the hybrids were not fertile, as a new and highly interesting form of fruit would doubtless have resulted had it been possible to establish a permanent race combining the strawberry and the raspberry.

effected. The raspberry was selected as the pistillate plant, and pollen was necessarily applied from whatever strawberry was at hand. It was impossible to choose as to the latter point, for the strawberry is for the most part out of season when the raspberry blossoms. Such material had to be used as could be found.

The pollination proved effective, and the raspberry plant produced a full crop of fruit.

There is no very marked immediate effect observable from such hybridization. The pulp of the berry seems not to be affected; but the essential seeds within the berry are enormously modified, as the sequel showed. For when the raspberry seeds were planted in the greenhouse, the young hybrid plants that come up in profusion had all the appearance of ordinary strawberry plants. No one who inspected them casually would suspect their hybrid origin.

The raspberry, the pistillate parent on which the seeds had grown, has leaves with five leaflets. But there was no leaf of this character among all the hybrids; without exception their leaves were trifoliolate like the leaf of the strawberry.

In other words, in the matter of foliage, the strawberry plant was entirely prepotent or dominant, and the characteristics of the other parent were latent or recessive.

When the hybrids were old enough they were carefully set out in rows in the open field on the Sebastopol farm. For a month or more after transplanting they showed no inclination to depart from the habit of the strawberry. To close inspection it might appear that the main stem was unusually thick, and that the leaves were a little more wrinkled than is usual with the strawberry, and their edges slightly more serrated. But aside from this, the hybrid plants were in appearance true strawberries.

About the first of June, however, the plants began to throw out underground stolons, whereas strawberry runners are normally on the surface. These stolons suggested roots of the raspberry, yet the new plants that sprang from them here and there were exactly like strawberry plants. So at this stage it would seem that the influence of the mother parent had been but slight.

But along in July came the transformation. Rather suddenly each main plant sent up two, three, or more strong smooth canes, which grew to the height of from two to five feet. These canes were absolutely thornless, as were all other portions of the plant; they were as smooth as strawberry plants in leaf and stem, but their form and manner of growth now departed

strangely from the traditions of the trailing parent.

Obviously the influence of the raspberry parent had at last made itself potent.

Some of the plants were yellowish, indicating that the berries would probably be yellow; others were reddish. There were no blossoms the first season, but the ensuing year clusters of blossoms of great size were put forth, some of the bunches being twelve inches in breadth—far larger than those usually seen on the raspberry. In a single cluster there were sometimes several hundred flowers. The individual blossoms were generally larger than the flowers of the raspberry, but slightly smaller than those of the strawberry.

In the center of each blossom was a miniature berry, which might be said to resemble either a strawberry or a raspberry, being so small that its exact characteristics could hardly be distinguished.

I was quite sure I had a valuable cross, and that at least one might be found among the many that would produce fruit. But in this I was disappointed; not a plant produced a single seed. The miniature fruit remained unchanged in size until it finally dropped from the bush in the fall.

The following season a few of the plants bore one or two fruits having two or three drupelets each, like mere fragments of a normal raspberry. But not a seed was found. The plants were as sterile as mules. So here the experiment ended, and the hybrid strawberry-raspberries followed the hybrid dewberries to the brush heap.

Why the Experiments Failed

If we now consider the results of these various experiments, it will be clear that they have certain elements in common. In all cases the hybridizing was effected between species that are botanically related. But in no case was the relationship between the mated forms very close. And this fact is of course of salient importance in enabling us to comprehend the results.

It is almost axiomatic to say that the hybridizing of plants generally becomes increasingly difficult in proportion as the attempt is made to cross more and more distantly related species. Even within the same genus it is very often impossible to produce a hybrid that is not sterile.

I might cite in further illustration of these difficulties the experiments through which I have hybridized the apple with the pear, and with the quince; the cherry with the plum; and the peach

with the almond, with the Japanese plum, and with the apricot, without in any of these cases producing a product of value. These crosses, like the ones just detailed, bring together racial tendencies that are too widely divergent to be harmonized.

It would appear that it is essential to the differentiation and perpetuation of species that bounds should be set on the possibility of producing a disturbing influence through hybridization. When plants, even though sprung from the same origin, have diverged so widely and for such periods of time as to produce forms differing from one another so greatly as, for example, the mountain ash, the apple, and the rose differ from the dewberry; or the strawberry from the raspberry—it would seem not to be of advantage to the plants to combine these forms.

The changes that would be produced, were such hybridization to result in virile offspring, would perhaps be too divergent to fit into their environment successfully. At all events the possibility of such crosses would constitute a disturbing influence of organic nature at least in some of its orderly character.

And so it appears, so far as may be judged from these experiments, that even when hybrids between these divergent forms are produced, the

offspring are generally sterile, and the results of the hybridization are not perpetuated.

Such, then, is the barrier that nature erects, in the interest of race preservation, between species that have already widely diverged.

But, on the other hand, we have seen many illustrations of the fact that when species a little more closely related are hybridized, the result may be not to produce sterility but to give added virility to the offspring.

We saw this illustrated, for example, when the walnut of the eastern United States was crossed with the black walnut of California. The hybrid progeny not only exhibited tremendous individual vitality, growing with great rapidity and to enormous size, but they produced an altogether extraordinary abundance of fertile fruit.

The hybrid variety thus produced—named, it will be recalled, the "Royal"—constitutes a new race that can more than hold its own against the parent forms.

And the reason for this seems to be that the two species of walnut had not become sufficiently divergent to introduce a greater diversity of conflicting tendencies than is consonant with racial progress when the strains are brought together.

But it will be recalled that when the California black walnut was hybridized with the English walnut—producing the "Paradox"—the results in this regard were quite different. While the individual offspring showed great vitality, they were almost sterile, producing only a few stray nuts in contrast with the profusion of the Royal hybrids.

And we may infer from this result that the California walnut and its remote English cousin have diverged to a point lying just on the border line of the limits of desirable racial mingling.

These limits have not quite been crossed as they have been in the case of the dewberry and apple tree, and the strawberry and raspberry, but they are being approximated; and there is no probability that the hybrid offspring of the black walnut and the English walnut could maintain itself through successive generations as a new race in the state of nature. At all events, its prospect of success would be a doubtful one.

The Application to the Human Species

It is more than likely, then, that the lessons taught by the unsuccessful experiments recorded in this chapter are quite as important as if they had led to what might appear to be more practi-

cal results. For they serve to emphasize a great fundamental truth of heredity, which has a more important bearing on the problems of racial development of all organic beings, including man himself. It has become more and more clear in recent years that the underlying principles of evolution apply to plants and animals alike, and that much may be learned about the better breeding of mankind from a direct study of the breeding of the lower organisms.

And as regards the particular case under consideration, it is scarcely to be doubted that we may draw important lessons from the obvious results of the hybridizing of plants to apply to the commingling of human races.

It is commonly held that the various existing races of man constitute a single species. But this classification was made under the influence of the old idea that sterility of offspring is a valid test of specific difference. No one nowadays holds that view, with regard to plants at any rate, and the view is probably no more valid in its application to a great number of animals, including man himself.

But, in any event, the question as to whether mankind constitutes a single species or several species is a matter of definition of no real importance. It is beyond question that the human

family comprises widely divergent races, and it is scarcely open to question that the divergences in many cases are so pronounced as to make hybridization between these races inexpedient, even though still possible.

The student of history tells us that the great civilized races of the past were all mixed races. This was true of the Egyptians, the Babylonians, the Greeks, and the Romans. It is true of the chief nations of to-day.

But the races that intermingled to produce the great peoples have always been somewhat closely related. No permanent good result has been generally achieved, for example, by the commingling of Mongolian and Aryan blood, or of Aryan with Negro. Such wide crosses must be expected to produce at least a measure of infecundity, and a commingling of racial tendencies too divergent to be advantageously blended.

The case is comparable to that of the Paradox walnut, even though it be not quite so extreme as the case of the hybrid strawberries and dewberries.

But what chiefly concerns us now is not the past history of mankind, but the present and future history; and in particular the history of mankind here in America. There is taking place

in our day what is doubtless the greatest migration in all history. The races of Europe are flooding into America, and there is a more pronounced commingling of racial strains now taking place on our soil than perhaps ever occurred in any one place, or in any single epoch, in the history of the world.

America owes its present greatness in considerable measure to the mingling of moderately divergent strains in the past; but this fact should not blind us to the menace that lies in the mingling of races that are too divergent to blend advantageously.

It is this thought that I would put forward as the most important suggestion that arises from the study of the hybridizing experiments which were unsuccessful in blending the hereditary tendencies of certain races of plants that were too widely divergent.

PLANNING A NEW PLANT

The First Steps in Practical Work

WITH many examples of the actual work before us, let us now proceed to investigate some of the interesting details of the methods, treating the subjects of pollination, grafting, plant affinities, fixing traits, selection, and spreading before us all of the processes which have been employed in more than 100,000 separate experiments.

The purpose has been to lead the reader, by easy and interesting stages, up to a point where a delineation of the actual processes may be most readily grasped. This will complete the consideration of general methods and, with the two preceding descriptions, give us a more intelligent survey of the work.

Some one has said that an artist is a man who can see the picture in the landscape.

In similar fashion it may be said that a successful plant experimenter is one who can see new

varieties of future plants when he looks at old existing varieties.

But of course the painter, whatever his constructive imagination, does not always see at first glance every detail of form and color that will ultimately appeal to him. Nor can the plant experimenter claim, by any manner of means, to know always from the outset just what his new plant creations, as a result of these new combinations, will be like. There are numberless instances, indeed, in which a plant experimenter who operates on a large scale may make various experiments in the combination of different species and varieties of plants; but, on the other hand, it is necessary in the pursuit of practical plant developments to have a tolerably precise idea in mind as to the particular direction in which progress is desirable.

Lacking such an ideal, the breeder of plants would be about as likely to produce new creations of value as an architect would be likely to construct a fine building by putting materials together at random without a carefully preconceived plan.

The mind of man has sounded no limits to time or space and is learning that all the varied forms and conditions which we know are intimately connected and interdependent upon past condi-

tions which have shaped their course and structure. The ever-varying influences of environment which have surrounded plants, animals, worlds or atoms have molded their characters and tendencies into their present condition. This we may call heredity or stored environment.

The more permanent aggregations with which we are familiar, like rocks, metals, air, water, and hundreds of others, seem very uniform and fixed in their characters, while, if chemically combined into the forms of animals or trees, they are quite able to vary before our eyes in aspect, habits, and characters in order to adapt themselves to the varying conditions of life; if plants and animals were not more pliable and alive than rocks and metals, they could not exist.

Even the apparent qualities of most chemical combinations which seem arbitrarily and permanently fixed may, when combined and placed under certain environments, develop unsuspected characters and tendencies.

Everybody knows, for instance, that the characters of iron are more fixed than those of plants and animals. The characters and habits of iron, lime, soda, and hundreds of other chemical substances and compounds can be fully depended upon; they will always act according to their in-

COMPLETE KIT OF POLLENIZING TOOLS

This shows all the apparatus required for elaborate experiments in cross-fertilization. The scalpel is used sometimes to cut across unopened blossoms —for example, apple blossoms—in such a way as to remove the pollen-bearing anthers all at once. Where the form of the flower does not permit this, the pincers are used to pluck out the stamens. The watch crystal is used on which to collect pollen, which is transferred to the stigma of another flower, either with the finger tip or with a camel's-hair brush. The other implements are sometimes required to manipulate a flower of peculiar form. The magnifying glasses are needed only with very small flowers. The use of the paper bags is illustrated elsewhere. The cardboard labels are to record the experiment.

herent qualities, but the chemical substances from which animals and plants are formed are so numerous and in such diverse combinations that their behavior is vastly more complicated and uncertain.

The structures which we call plants and animals make use of the chemical combining and separating forces of nearly every substance so far discovered in the universe.

Nature has been carrying on selective world-wide breeding of plants and animals on a constantly widening scale for millions of years; but nature does not care for sweet corn, melons, Bartlett pears; luscious, juicy, fragrant peaches; large, early, sweet cherries; thin-skinned, seedless, juicy oranges; large grapes of many seasons, colors, and flavors; pineapples with their delightful aroma; prunes with sugar content sufficient to preserve them while drying; large, crisp cabbages; head lettuce; "Quality" asparagus; self-blanching celery; double roses; varicolored carnations; cactus dahlias or wonderfully colored gladioli; cannas and lilacs with new perfumes and a beautiful varied range of splendid color effects, or the farmers' crops of varied grains and potatoes which now are, in most cases at least, a hundred times as productive and of almost infinitely improved qualities.

But man has, at first unconsciously and later consciously, produced all these marvelous improvements and ten thousand others and is now making and will make improvements in everything, plant and animal, which is useful to him; not by nature's method of selective breeding for the continuance of life at any cost, but for *definite purpose* to supply the world with food, clothing, shelter, and luxuries.

"In what percentage of cases have you achieved the ideal at which you aimed in the production of new varieties of flowers or fruits?" is asked.

The question is almost impossible of definite answer. When I first commenced, doubtless a very small proportion of these experiments came out as expected. But now, with years of experience to guide me, it may be said that I practically always get something not far different from what is desired. In most cases the result comes just about as expected. But this is because I am working with plants that I have previously tested.

With a new plant there is sometimes doubt. But if it is a case of poppies or walnuts, plums, corn, peaches, wheat, carnations, potatoes, and a thousand or more others that have been fully tested, I know just about what to expect.

At best, however, I am very often reminded that each species has its own individuality and that even the most familiar plant may hold surprises in store for us.

The Rough Sketch

"But just how do you start out when you are seeking to create a new form of plant life?" I am constantly asked.

And here again the answer is difficult. Everything depends upon the ultimate object. If I am seeking merely to test the possibilities of making certain crosses, or as it were feeling my way along new channels, it is more or less like a person groping in the dark.

This form of vague experimentation is often full of interest. Instances have already been given of what may come to pass when we combine plants of widely separated species or of different genera. The reader will recall the case of the petunia with the tobacco habit and of the dewberry crossed with such remote cousins as apple and pear and mountain ash. These experiments were made without a clearly defined object—except to ascertain whether it was possible to combine plants of such diverse character.

And the results of these experiments, while of very great scientific interest, were not practically

successful in a commercial sense and were not primarily expected to be.

I recall reading an address by the late Professor Newton, a distinguished American astronomer, on the subject of "dead work," in which he emphasized the fact that the main bulk of the experiments which any scientific worker must make will lead to no definite goal. A large part of the time of every experimenter must be given up to following trails that lead nowhere in particular or that end in *cul-de-sacs*.

The work of the plant experimenter is no exception, but there is always an incentive to further effort in the knowledge that a path that seems to lead only into impenetrable mazes may presently bring one out into the light. To make the application to one illustrative case among many: For twenty or more successive seasons I attempted to hybridize certain species of Solanum before I finally succeeded in effecting a cross that gave me a few seeds from which sprang the new race of sunberries.

But it must be understood that the main bulk of my experiments are not made in any haphazard manner.

On the contrary, my most important results have been attained by continuing the experimentation along rigidly predetermined lines and by

methods of hybridizing and selection that my earlier work had fully established. Having tested the usual limits of making new plant combinations, I was presently able, like any other trained technician, to apply the knowledge thus acquired toward far more definite results than were at first possible.

In the case of the Shasta daisy, the plans were all laid out beforehand as to just what type of flower I wished to produce.

The ideal of a white blackberry was also, of course, a perfectly precise and definite one.

Obviously the fragrant calla, the stoneless plum, the early-bearing cherry, the sugar prune, and the spineless cactus are other instances in which the ideal pursued was as clearly conceived and as definitely outlined in advance of my earliest experiments as a cathedral is outlined in the mind of the architect before he commences his preliminary drawings.

In one case as in the other the details may be modified as the work progresses, but the general idea of the structure aimed at—be it new fruit or new building—must be conceived with a scientific definiteness from the outset. My original conception of a new plant creation, in the cases outlined and in a large number of others, certainly bore as close a resemblance to the final

ONE OF THE ORIENTAL PEARS

The Oriental pears have not the characteristic shapes of the European pears. The latter were presumably modified in shape through selection at a comparatively recent period. The original home of the pear was, without doubt, central Asia, and the fruit was carried into Europe, probably in prehistoric times. The pear is often characterized by having a fibrous or woody deposit in the skin and near the core, indicated by the dotted appearance of this Oriental specimen.

product achieved as the first rough drawing of the architect ever bears to his finished plans.

"But how do you *begin?* What is the *very first thing?*"

The "very first thing" I have already described —it is the conception of an ideal, a mental picture of the new plant form desired.

Clues to Be Followed

It has occurred to me, for instance, that the cherry crop is not what it might be. I have learned that there is a steady market for early cherries and that a difference of a few days in the time of marketing may make a difference of more than one hundred per cent in the price.

And so I ask myself, why not create a new cherry that shall be ready for shipping at least a week or two earlier than any cherry now in the market.

Of course, an early cherry must have a number of other desirable qualities—large size, rich color, lusciousness of flavor. Knowing this at the outset, I soon learned that it is desirable also, from the standpoint of the shipper, that the cherries shall grow on short stems. I know that the tree producing them must be hardy, capable of withstanding both cold and wet winters, and dry summers, and that it must have an inherent vitality

that will make it resistant to most of the attacks of insects and fungoid pests.

Next I ask what warrant there is for supposing that such a fruit structure can be built.

And here the answer is supplied solely by the use of imagination in connection with an inspection of the existing races and varieties of cherries. On examining the best fruits already in the orchard, we find that there is a large measure of variation between the cherries grown on different kinds of trees, as well as between the individual specimens on the same tree.

In imagination I look back far into the past and inquire as to the racial history of this fruit and am led to believe that certain among the ancestors of the cherry have grown in semitropical climates, and I know that even in the present day there are species, doubtless sprung from the same original stock, that grow far up into Canada.

Why is it that the cherry shows such a propensity to vary? The answer is found in the assumption that the existing cultivated races carry in their veins, so to speak—tendencies drawn from varied strains of a mixed ancestry.

And I know that it should be possible, by accentuating the tendency to variation through further hybridizing, and by careful combinations and selections, to attain the object sought.

It will be obvious, then, that I am not preparing to make bricks without straw and am counting well the materials with which I must work, just as the architect from the first stroke of his pencil bears in mind the materials of the future cathedral.

We do not imagine that an apple tree can be produced from cherry trees, any more than the architect assumes that he can build a marble cathedral out of bricks; well knowing that there are sharply defined hereditary limitations beyond which the cherry cannot be made to go within any such period of time as that limiting the experiment.

In other words, I do not ask the impossible, although it has often seemed to some of my less intelligent critics that I have asked the highly improbable.

But the results attained are in themselves very sufficient answer to these critics. If my vision has in some cases been the clearer, it is merely that my knowledge of plant life, drawn from the school of experience, has been wider.

To the uninitiated observer it may have seemed that I set no limits to the transformations attempted. In reality, my plan has always from the outset recognized most definite limits—although often enough the limits as conceived were

AMERICAN PEARS WITH BLENDED HEREDITIES

When the types of pears from the Orient and the Occident are crossed, the hybrid offspring show wide variation of form, texture and flavor, particularly in the second and subsequent generations. This picture shows characteristic specimens of such mixed heritage — good material for the development of new varieties.

quite different from those that had been set by theoretical botanists and compilers.

Aid from Galton's Law

In attempting to estimate the possibility of improvement in a given form of plant life, it is of value to recall the formula put forward by the late Sir Francis Galton; a formula often spoken of as Galton's law.

According to this estimate, the hereditary traits of any given organism are so intermingled that we may assume as a general rule that offspring of a given generation will inherit about half their tangible traits from their parents, one quarter from their grandparents, one-eighth from their great-grandparents, and so on in decreasing scale from each earlier generation.

Stated otherwise, according to this rule, we should be able by observation of the parents of any given organism, to see presented half of the traits of the offspring, but we may expect that the offspring will manifest, as the other half of their inheritance, traits that have come to them through the process of reversion or atavism, from remote generations of the ancestral strain.

And this obviously gives opportunity for the appearance of an enormous variety of traits in

any given generation that were not manifested in the preceding generation.

Thus any given individual has normally, as a moment's reflection will show, four grandparents, eight great-grandparents, sixteen ancestors in the generation before that, then thirty-two, sixty-four, one hundred and twenty-eight, and so on in a geometrical ratio with each remoter generation. So the normal ancestral clan of any one of us numbers more than a thousand different individuals within the relatively limited period of time compassed by ten generations.

And, according to the estimate of Galton, to which numberless cases of atavism give force, certain traits and tendencies of each and every one of these ancestors may make themselves manifest in the personality of any given descendant.

Galton's studies, upon which his formula was based, were chiefly made with reference to human beings, but we now know that the laws of heredity apply with equal force to all kinds of living organisms, including plants; and whatever the limitations of Galton's law as a precise formula, there can be little question as to the general truth of the principle that he invoked.

Hence the value of that search in imagination for the ancestors of our cherry in their widely

separated habitats and with their widely diversified traits and habits.

But of course in making practical studies for the development of the mental blue print with its forecast of qualities of our new cherry, we must perforce be guided largely by the observed qualities of the parent stock with which we deal. Precisely what were the qualities of the remote ancestors we can only infer. But we can see for ourselves what are the qualities of the fruit before us.

We know, then, pretty definitely what we may expect as to one-half the traits of a hybrid that will result when we cross two varieties of cherries in our orchard. The other half must be somewhat a matter of conjecture, to be revealed by the actual product or, as is practically the case, by succeeding generations.

What we actually do, then, in practice, is to take pollen from a variety that has been observed to bear fruit somewhat earlier than neighboring trees, and with this pollenize flowers of other varieties that have been observed to produce fruit of exceptionally good quality. Pollination accomplished, by the method elsewhere described, we can only mark the branch and the individual fruits so pollenized for future identification, and await results.

TEN CORN VARIATIONS

The smallest figure, at the lower left, shows the grain of an improved teosinte, the primitive type of corn. It has no rachis or cob, the kernels shelling out like wheat. The other figures show a few gradations from this primitive to field corn, as developed through selection. We may suppose that the corn passed through some such stages as these in the course of its long evolutionary development.

The seed thus secured will be planted next season, and in due course we shall have a seedling which, when grafted on another tree to speed its maturing, will come to blossoming time—after another period of waiting—and finally show us the first fruits of our experiment.

From this fruit we shall raise a new generation of seedlings which will reveal to us beyond peradventure a varied assortment of ancestral traits that the parental forms of our first hybridization did not show. And from among these diversified forms we shall be able, by a long series of selections and new combinations, to make our way toward the attainment of our original idea.

The precise steps and the varying details through which this may be attained will be discussed in other chapters. Here we are concerned only with the general outline, and, this having been presented, we may leave our cherry in this interesting stage of partial construction.

To be sure we have not apparently advanced very far toward our ideal in these two generations; but in this our case is only comparable, after all, to that of the architect who, when he has planned a building that shall ultimately tower toward the skies, must be content to see the workmen first begin digging in the opposite

direction, to lay foundations far beneath the earth's surface.

This matter of the very doubtful result of the first stages of a hybridizing experiment should be emphasized, because otherwise the amateur is pretty sure to become discouraged at the outset and to proceed no further.

Many an experimenter has given up a quest because when the two varieties of plants were crossed the offspring seemed inferior as to the desired quality to either of the parents. But the experienced plant breeder knows that this is very often to be expected and that he should not be in the least discouraged by this result. It is generally necessary to go on to the next generation before we can hope to discover the real possibilities of the experiment.

The simple fact is that, where varieties or species of plants that differ markedly as to certain qualities are combined, the offspring very frequently seem to present what has been spoken of as a mosaic of characters rather than a blending. It may and very commonly does manifest, as regards any given quality, the influence of one parent seemingly to the exclusion of the other.

A familiar illustration of the same rule may be observed when a person having black eyes

marries one having blue eyes. It is obvious that no individual child of this union can have both black eyes and blue eyes. In point of fact, it is a matter of common observation that the offspring in such a case will have dark eyes.

But it has also been observed that the blue eyes of one of the parents may reappear in the second generation.

The tendency to blue eyes was entirely subordinated or submerged in one generation, yet it was by no means eliminated, as its reappearance in the next generation clearly proves.

Similar instances without number may be studied from our plant experiments; for example, the case of the white blackberry. If flowers of this kind are fructified with pollen from flowers of a blackberry of the usual color, the hybrid progeny of the first generation will all bear black fruit.

The quality of blackness has proved prepotent or dominant, and the opposed quality of whiteness has been totally subordinated so far as this generation is concerned.

But if these black hybrid blackberries are cross-fertilized, from the seed thus produced there will spring a generation of brambles, some members of which will in due season produce

CORN TEOSINTE HYBRIDS SEVENTEEN FEET HIGH

Corn was originally a subtropical plant, and the primitive teosinte is a plant of rather tall growth. By hybridization and selection giant varieties have developed here which grow with tropical luxuriance, reaching a height of seventeen feet. Superior for stock feed, but having small, inferior ears.

white fruit precisely like that of the maternal ancestor.

Such, it will be recalled, was indeed the experience in the development of the new race of white blackberries.

To instill good qualities of fruit into the inferior original berry, it was necessary to cross with the large and well-flavored Lawton blackberry.

The immediate result was seemingly to obliterate the white-fruiting tendency altogether.

But a wide experience of similar instances led me to continue the experiment, which for the moment seemed to be carrying me away from the ideal of a white blackberry; and the principle of reversion came to my aid in the next generation and gave, as will be recalled, a berry that combined the light color of one of its grandparents with the size and flavor of the other.

As already suggested, it aids the memory, and helps to give tangibility to the facts, to recall the Mendelian phrase which speaks of blackness versus whiteness in such a case as constituting a pair of unit characters; naming blackness as the dominant and whiteness as the recessive feature; and which gives assurance that a fruit which shows the recessive character of whiteness

in the second generation will thereafter breed true, thus affording us evidence of definite progress toward the ideal of our experiment.

Aid from Unit Characters

As the principles that govern these cases are of very wide application, it follows that there is very great advantage from the standpoint of the plant developer, in the discovery of pairs of unit characters and the demonstration of their relation toward each other as regards dominance and recessiveness.

An interesting illustration of this is afforded by the experiments made by Professor R. F. Biffin, of Cambridge University, in the successful attempt to develop a new race of wheat.

Professor Biffin through a series of experiments showed that when beardless ears of wheat are crossed with bearded ones, the beardless condition proves dominant, so that all the offspring are smooth-eared; but that the recessive quality of bearded grain reappears in the second generation.

The same thing held true for various other pairs of unit characters, such as red chaff versus white chaff, red grain versus white grain, hollow stem versus solid stem, and the like.

Professor Biffin was able to make an immediate practical application of his experiments through which he developed a new race of wheat that is proving of great economic importance. It appears that the best races of British wheat have been peculiarly susceptible to the fungous pest known as rust. There are, however, certain races of wheat that are immune to the pest; but unfortunately these produce a very poor quality of grain.

Professor Biffin found that susceptibility and immunity to rust constitute a pair of unit characters, in which susceptibility is prepotent or dominant.

When he crossed the susceptible grain with the immune one, he therefore produced an entire generation of susceptible grain.

His experiment had seemingly gone backward, quite as in the case of my first generation of white blackberries.

But in the ensuing generation the recessive character of immunity reasserted itself; and, combined with this desired character, in a certain proportion of the progeny, there appeared the other desired quality of a good variety of grain of fine resisting qualities.

So by the application of this principle of the segregation and recombination of unit charac-

CORN SELF-POLLINATED AND CROSSED WITH TEOSINTE

The upper ear is an ordinary ear of sweet corn, presenting no marked peculiarities. The lower ear was developed on the same stalk by pollenizing the corn silk with pollen from the primitive type of corn called teosinte, which is illustrated on earlier pages of the present volume. The influence of the pollen parent is clearly shown in the modified form of the kernels. With most plants the pollen does not directly affect the fruit, but corn is a notable exception in this regard.

ters Professor Biffin produced a new race of wheat in two or three generations, and this new race of wheat breeds true.

We shall see this principle illustrated over and over in connection with the long series of my plant experiments.

In case of the wheat, as in that of the white blackberry, the process was relatively simple because we were dealing only with two pairs of unit characters. Moreover, the case of wheat is further simplified by the fact that this plant is self-fertilized and under conditions of cultivation has become a very fixed race, little subject to variation.

When we deal with races of fruits that tend to vary almost indefinitely, and when further we are concerned with ten or a dozen unit characters, the matter becomes vastly more involved, as we have previously seen illustrated.

But the amateur will do well to begin his experiments with simple cases, dealing with only a single quality, say a particular color of flower, that he may thus learn to distinguish the principles here enunciated. In due course he may go on to apply these principles to more complicated experiments in plant combinations. But unless he learns at the outset that certain characters that are submerged in the first hybrid generation

will inevitably reappear in the second, he will constantly blunder in his interpretation of tentative results.

On the other hand, when he has learned to gauge his second-generation hybrids correctly, he is on the highway to success as a plant experimenter.

PLANT AFFINITIES

Choosing the Lines of Least Resistance

"WHY do not plants cross in a state of nature?" a friend asked me. "You seem to get most of your new varieties by crossing old ones. Why does not nature take a leaf from your notebook and produce new species in the same way?"

And I was able to inform this inquiring friend, much to his surprise, that the method he suggested was one that nature had practiced from the beginning, and is constantly practicing all about us.

We were standing near the gateway of the Sebastopol place.

"Just over by the roadside," I said, "you may see for yourself precisely such an experiment in plant combination as I have made in the case of thousands of plants. Do you see those tarweeds? Doubtless you are familiar with them.

"One of them has large showy flowers, the other small and inconspicuous ones. The botanist calls the large-flowered species *Madia elegans*, and the other *M. sativa*. The two species do not look much alike, and some botanists even classify them in different genera.

"If you look at all closely you will see that there is a third form of plant, bearing some resemblance to each of them, growing among the others, and that this is a natural hybrid between the two.

"If you examine this hybrid, you will find that its branches are less spreading than those of its large-flowered parent, although not upright like those of the other parent; and that the stem is stouter than that of either parent. As to foliage, the hybrid plants have larger and thicker leaves than those of the large-flowered tarweed, more closely resembling the other species in this respect, but the ray flowers are intermediate in size and shape as well as color, the reddish-brown that characterizes the flower of the more conspicuous parent being reduced in the hybrid to a spot just in the top of the tube.

"So here you are probably witnessing the creation of a new species in nature. You, of course, are an evolutionist and therefore are aware that all species of plants as well as animals have been

evolved in past ages by a development from earlier forms, but you very probably supposed that this creative process has now come to a standstill. Let me assure you, then, that this process is going on to-day very actively, in all probability quite as actively as at any time in the past.

"Species of plants in a state of nature are constantly crossing and new species are being developed under our eyes.

"There is nothing anomalous about the case of the tarweeds, although they afford a very interesting illustration of the development of which I speak. The same thing may be observed in the case of certain genera of the mint family. Here in some cases the hybrids thrive almost to the entire exclusion of the parent species. In other cases they gradually disappear, being too unstable to establish themselves by seed.

"Everything, of course, depends upon the qualities of the hybrid. If it is well adapted to the environment it survives. If better adapted than its parents, it probably displaces them altogether. But, on the other hand, if the hybrid is less well adapted than the parent forms to make its way in the world, it is of course weeded out by natural selection."

In response to a further query I mentioned for my friend, among plants that often cross in a state of nature, the various species of the genus *Rubus,* including the blackberry, raspberry; in the tribe of wild roses and crab apples; the California lilac, the various members of the oak tribe, the willow, the strawberry and the huckleberry; nor are these all—the list might be almost indefinitely extended.

Indeed, it is my firm conviction that crossing between natural species is a phenomenon of almost universal occurrence.

No other equally plausible explanation has been given of the appearance of what may seem to be spontaneous varieties or forms that furnish the material for the operation of natural selection, and are thus among the bases of organic evolution.

It is true that such a suggestion as this would have seemed heretical not very long ago; but vast numbers of experiments in the combination of different species, and even representatives of different genera, in my orchards and gardens have afforded a mass of evidence that no one can ignore. So to-day it is coming to be recognized quite generally that the combination of wild species is one of nature's conventional methods of producing variability, and, as it were,

testing out the environment by supplying new forms that come in competition with the ones already developed.

Limits of Hybridizing

But why then, you will perhaps ask, does not the production of new forms between natural species take place so universally as to disturb the entire scheme of organic nature. In point of fact, the zoölogist and the botanist are able to describe vast numbers of species, each of which has certain fairly well-defined characteristics and differs in certain definite regards from other forms.

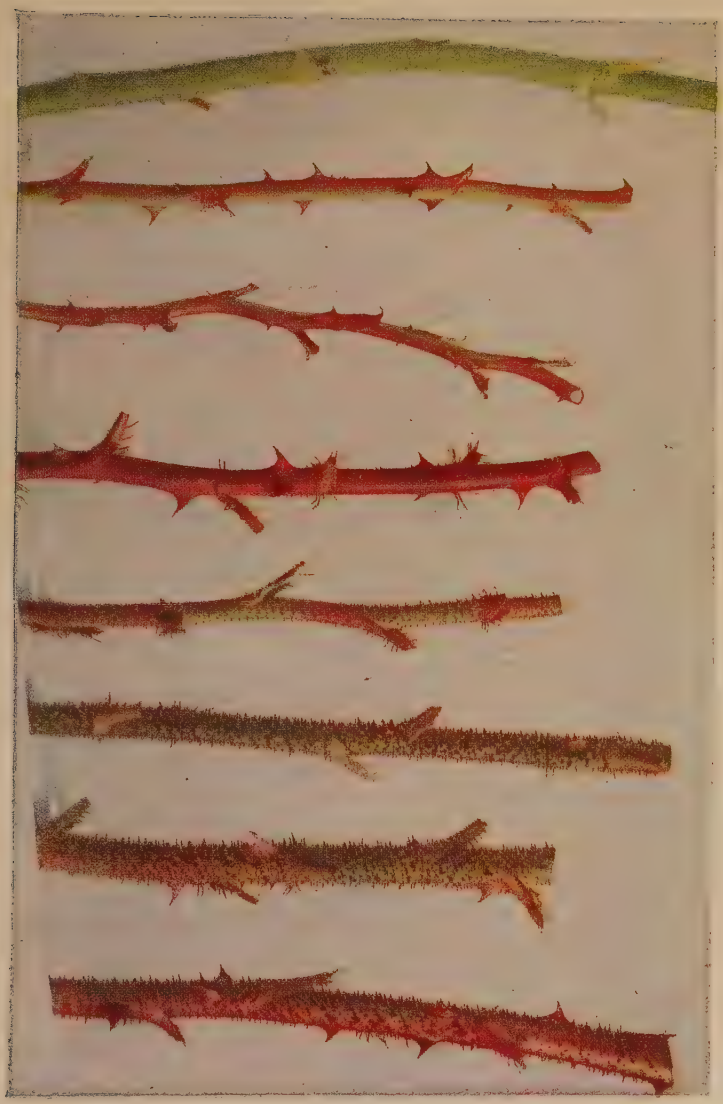
It is true that the more closely the matter is studied the more commonly varieties are found that manifest characteristics intermediate between those of the supposedly fixed species. But even when these are taken into consideration, it still remains true that the word "species," as applied to a vast number of familiar forms of vegetable and animal life, has a pretty definite and tangible meaning.

How is this possible, if the interbreeding of species is a universal phenomenon?

The answer is found in the facts (1) that the hybrid forms produced, when species in nature are crossed, for the most part quickly disappear

SOME STEMS OF BLACK-BERRY-RASPBERRY HYBRIDS

The direct-color photograph print opposite shows some typical stems — varying in color, shape, and thorniness. The rose, the blackberry, the apple, and sixty-two other plants, dissimilar in appearance, are all members of the same family, and often give evidence of the possession of common family traits.



because they are not an improvement, from the standpoint of adaptation to their environment, on the parent forms; and (2) that limits are imposed by the relative lack of affinity of one species for another.

As to the first point, it must be recalled that each existing species has been produced only after long generations of struggling against adverse conditions. Constantly there is a tendency to variation within certain limits even in the case of the most fixed species. Such variations constitute tests of the fitness of the species to live in the environment in which it finds itself. Favorable variations are preserved by natural selection, simply because they have the capacity to outgrow the original form, or outlast it in times of drought or other hardship.

And so every existing wild species proves by the very fact of its existence that it has a large measure of adaptability to the existing environment.

It is always improbable, then, in the nature of the case, that any new intermediate form, such as would arise from the combination of two allied species, will be better adapted to survive than the parent form. Such cases do arise, else we should have no new species, but in general the rule holds. So we may fairly count it excep-

tional if a combination between natural species survives beyond the first or second generation.

The struggle for existence is always keen, and the individual organism that lacks ever so little of equaling its fellows in vitality and responsiveness to its environment must inevitably perish.

Nevertheless, the experiment of producing new forms through the combination of old ones is perpetually being made, and must continue to be made, if existing forms are to remain plastic, ready to take advantage of the changed conditions of environment; that is to say, ready to evolve in future as they have evolved in the past.

But there are limits beyond which this perpetual experimentation with new nascent species could not advantageously be successfully carried, and so nature puts a sharp limitation upon the extent to which the experiment may be undertaken.

Affinity Founded on Cousinship

And this is done by the simple procedure of making it increasingly difficult for species to interbreed in proportion as the species become divergent in character.

Tarweeds, for example, may interbreed among themselves, and various species of mint may similarly interbreed, but no species of tarweed

would combine with a species of mint. One member of the rose family may cross with another—blackberry with raspberry, let us say, or quince with apple; and in the same way different species of oak may interbreed; but the combination of apple or blackberry with any species of oak is unthinkable.

Similarly, I have been able to cross peach with almond, and almond with plum, and plum with apricot; also apple with quince, and quince with pear. Stone fruit with stone fruit, and seed fruit with seed fruit—but not seed fruit with stone fruit.

In a word, the possibility of cross-fertilization between species is conditioned on a certain closeness of relationship, which we speak of as affinity.

This is a matter of actual genetic relationship. All members of the rose family, for example, have branched from the primal ancestral stem at a period much more recent than that at which the common ancestor of the present-day apple and rose and blackberry branched from the primal stock of, let us say, the oaks.

In the broadest view, there is a cousinship between all species of plants; just as there is relationship between all the twigs of an actual tree. But the species of an existing genus may be likened to twigs on a single branch; other

genera representing different branches which may diverge in opposite directions, and only come together at the trunk.

Then, too, there is a time element involved. Species that are closely similar in character and appearance are those that have branched from the ancestral stem in relatively recent epochs; species more distinct trace their cousinship through remoter lines; and forms so widely diverse as to be placed in different orders have been separated for still longer periods. And we must suppose that in each generation the new forms have taken on a modicum of new traits, and have tended to fix the divergence of earlier traits through which they attained specific difference.

In due course, then, it comes to pass that a given form has branched so widely from its cousins that the harmony of purpose, so to speak, once obtained between them no longer obtains.

The racial memory as to their common ancestry has become blurred, if the phrase be permitted, and each species has become so fixed in its own manner of life that no compromise between them would be possible.

And so we find that it becomes increasingly difficult to cross species that are obviously widely

divergent in form of stem and foliage and flower, and that in a vast number of instances any attempt to combine these forms is altogether futile.

It must be understood, however, that it is by no means always possible to predicate, from observation of a given pair of more or less distantly related species, whether or not the two would be mutually sterile. Sometimes the experiment results in a surprise, and we are able to produce offspring when the possibility of such a cross seemed altogether improbable.

Such was the case, it will be recalled, with my experiments in hybridizing the dewberry with the pollen of the apple, pear, rose, and mountain ash. Such was the case also with the cross which resulted in producing the sunberry, and with that which developed the plumcot.

In each of these cases the pistil of one plant accepted the pollen of the other, as it were, unwillingly. But persistent effort effected the desired result, and in the three instances last mentioned fertile offspring were produced. Possibly these might not have survived in the state of nature, but under the conditions of intelligent selection they provided the foundation for the development of what may be considered new species.

Plant Antagonisms

The characteristics that make it impossible to cross two species that have varied beyond certain limits are sometimes physical.

Thus it may chance that the two species have developed the habit of blooming at different times. If the flowers of a given species are altogether out of bloom before the flowers of another species open, it is obvious that, in a state of nature, a cross between these species will not occur, however close their affinity. Similarly there are two closely related species of evening primrose that do not cross under natural conditions because the flower of one opens only for a brief period at midday and that of the other only during the night and early morning.

Again it occasionally happens that the physical structure of the style which carries the pollen tube to the ovules is such as to prevent the carrying out of this essential process. In the case of a large pollen grain and an exceptionally slender style, it is possible that the fructifying substance of the pollen is debarred from finding its way to the ovule.

Such cases are probably exceptional, however, and the usual barrier between species is not perhaps so often physical as chemical. That

is to say, the antagonism is inherent in the plants themselves.

Allied species are of such chemical constitution that the protoplasm from one combines readily with protoplasm from the other.

In the case of more widely divergent species it may come to pass that the juices of one plant are actually poisonous to another. In such a case it is futile for the pollen grain and pistil to meet, because no fertilizing influence will be transmitted.

Even if the degree of chemical antagonism developed has not reached a stage that makes fertilization wholly impossible, it may be sufficient to prevent the development of a thrifty offspring.

Or, as is quite usual, it may result in the sterility of the hybrid progeny, and thus put a barrier upon further advance along that line.

If proof were needed that such a chemical antagonism prevents the cross-fertilization of species separated too widely, further evidence may be found in the negative results that attend the attempt to graft a branch of one of these species upon the stock of the other.

Generally speaking, it will be found that species that cannot be cross-fertilized also cannot be cross-grafted.

In exceptional cases it is possible to effect the graft where efforts at crossing have proved futile. Such was the case, for example, with my grafted tomato and potato vine. But, in general, the plant that refuses to mate with another plant refuses also to accept its stem as a companion organism when grafted or budded.

However carefully the grafting experiment may be performed in such a case, the uncongeniality between stock and cion is soon made manifest. The surfaces do not unite; or if union takes place there is but slight tendency to grow; or the cion does not thrive, and is presently blighted.

There are all gradations—from actual poisoning in which there is no tendency whatever to unite, to a partial or even temporarily complete union, followed by separation even after years of growth—according to the degree of antagonism.

These chemical and mechanical antagonisms between the tissues of the plants themselves afford the surest evidence of the long period of time during which the two species have lived under more or less divergent conditions, and have been occupied, each in its own way, in the development of new characteristics. Yet that such intimate differences of constitution should obtain between species that show many outward points

of resemblance must always be matter for surprise to the plant lover whose attention is called to it for the first time.

That this intimate record of grades of cousinship should be permanently fixed in the protoplasm of the plant itself is one of the most mystifying and thought-compelling of biological revelations.

If anyone were to doubt that the intimate chemical structure of plant protoplasm and plant juices may thus be depended on to reveal genetic relationships, and to mark nice shades of distinction between allied forms, evidence from a quite alien field might be cited that would set the matter at rest.

Evidence from the Animal World

The evidence in question is furnished by an extraordinary series of blood tests through which Dr. G. H. F. Nuttall, the American Professor of Biology at Cambridge University, has traced the intimate relationship of large numbers of animals of different orders.

By inoculating rabbits with the blood of different species of birds, reptiles, and mammals, Dr. Nuttall was able to develop an extraordinary serum with which the intimate constitution of the blood of other species of animals could be

tested. He thus demonstrated, for example, that lizards and serpents are more closely related than turtles and crocodiles, but that all these reptiles are nearer to one another than they are to birds, and nearer to birds than to mammals.

He showed that the dog carries in every drop of its blood chemical proof of closer relationship with wolves, and foxes, and jackals of every species than with any member whatever of the cat family. Similarly, all cats—tigers, lions, leopards, along with the domestic tabby—give proof, in the chemical constitution of their blood, of a common origin. And, bringing the comparison still nearer home, the blood of man is more like that of the chimpanzee, the gorilla, and the orang, than it is like that of any other creatures; and the monkey tribes of the Old World are more manlike in the constitution of their blood than are the monkeys of the New World.

Dr. Nuttall's experiments comprised sixteen thousand individual tests, with a total of at least 586 species of mammals, birds, reptiles, batrachians, fishes, and crustaceans, coming from all parts of the globe. The biological implications of his experiments have been commented upon as follows:

"Doubtless some hundreds of thousands of years have elapsed since the direct ancestors of

men branched from a common stem with the direct ancestors of the gorilla. There has been no blending of blood in the intervening centuries. Cats have been cats and dogs dogs from geological epochs so remote that we hesitate to guess their span in terms of years. So the intimate chemical qualities that denote man or ape or cat or dog, each in contradistinction to all the others, must have been transmitted unmodified through countless thousands of generations.

"It taxes credulity to believe that such intangible properties could be transmitted unmodified through the blood streams of such myriads of individuals; but the evidence of the test tubes proves that these are the facts.

"What makes the marvel greater is the fact that the bodies of the animals have meantime been so modified as to develop utterly divergent species—for example, the lion, the tiger, the puma, the leopard, and the house cat; different types of dogs, wolves, foxes, and their allies. But in each case some intangible quality of the blood remains unchanged to prove the common origin. Blood is indeed thicker than water."

The bearing of these extraordinary experiments upon the case in hand will be obvious.

If animals carry in their veins generation after generation, through untold thousands of years,

A SHIRLEY POPPY—SHOWING REPRODUCTIVE ORGANS

The petals of a flower are designed to attract insects. The essential organs are the pollen-bearing stamens and the pistil inclosing the ovule at the center of the flower. This picture shows the large number of stamens of the poppy, each with a terminal anther, bearing pollen, growing in a circle about the pistil with its curiously rounded end, called a stigma, designed to receive the pollen. The office of the insect is to transfer pollen from the stamens of one flower to the pistil of another.

these intimate chemical conditions, then the same thing may well be supposed to be true of plants. And so the affinity shown between species that can be crossed, and the antagonism between species that refuse to cross can be explained on the basis of a fundamental intrinsic quality of the protoplasm, the foundation substance of life.

This gives us a more profound and comprehensive appreciation of the word "affinity" as applied to various species of plants than we could otherwise have.

It also makes it in a measure comprehensible that the traits of remote ancestors should be carried latent in the tissues of the germ plasm, as we have seen that they are carried, for untold generations.

The Continuity of the Germ Plasm

This germ plasm, which is the connecting link between one generation and another, is passed on, according to the most prevalent idea, from parent to offspring, generation after generation, subject only to such modifications as may from time to time be imposed through environing influences.

The physical mechanism that underlies this transfer we shall have occasion to examine in another connection when we discuss at some

length the theories of heredity. For the moment it is enough to reflect that as the offspring in each successive generation spring from the parent, the germ plasm may be thought of as a continuous stream uniting the remotest ancestor of any given strain with the most recent descendant.

Every tree in the orchard, for example, carries within its tissues a portion of protoplasmic chemical matter that has come down to it through an almost infinite series of growths and divisions in unbroken succession from the first tree that ever developed on the earth—or, for that matter, from a vast series of more primitive organisms that were the progenitors of the first tree.

And while this stream of primordial protoplasm has been changed by an infinitesimal quantity in each successive era, it has retained even to the present the fundamental characteristics that it had from the outset.

That such is the case seems little less than a miracle; that an almost microscopical speck of protoplasm which we term a pollen grain should contain the potentialities of thousands of generations of ancestors, and should be able to transmit them with such force that the seed growing from the ovule fertilized by that pollen grain will

inevitably produce, let us say, an apple tree, not a pear tree or a plum, is beyond comprehension.

Yet we know it to be true.

And so the plant breeder who consciously merges two different protoplasmic streams when he brings the pollen of one flower to the pistil of another, participates in what must be considered the most wonderful of all experiments.

He brings tokens out of an almost infinite past to blend with the divergent tokens of another ancestral stream no less ancient.

And it is not strange if he feels a certain impulse of elation when reflecting that his conscious efforts have thus brought together ancestral tendencies that have long been separated and that now will appear in new combinations—stimulating such interplay of life forces as may bring into being plant forms that may be described, without violence to the use of words, as new creations.

That the intimate record of cousinship, in all its grades, should be permanently fixed in the protoplasm of every living thing, is a thought-compelling biological revelation.

PRACTICAL POLLINATION

A Survey of Working Methods

ONCE upon a time—it may have been about the year five million B. C.—a plant imbued with nascent wisdom made a tacit compact with a fellow creature of the world at large that was fraught with strange and fateful meanings for races of beings yet unborn.

The fellow creature in question was at that time probably the most highly developed citizen of the world, although in modern terminology he would be termed "merely an insect." The compact the plant made with him was to the effect that one should manufacture sweet nectar and freely supply it as food; and that the other in return should carry the fructifying pollen grains from flower to flower.

Doubtless no more important compact was ever entered into in the history of animate creation before or since.

For out of this compact grew the rivalry that stimulated development and made possible the

POLLEN-BEARING PUMPKIN BLOSSOM

Many plants bear pollen and ovule on separate blossoms, so that self-fertilization is impossible. This picture shows a pumpkin blossom with the modified and coalesced stamens at its center bearing a quantity of pollen. The insects in visiting the blossom carry the pollen on their bodies or feet and transfer it to other flowers.

evolution of the whole race of plants that bear beautiful flowers and exhale sweet perfumes. But for this eventful alliance, there would never have developed in the world a conspicuously colored or a fragrant flower of any kind.

And it requires no argument to show that a world without beautiful and fragrant flowers would be a world robbed of a large share of its attractions as an abiding place.

But that is not all. The alliance between insect and flower did not merely suffice to give us things of beauty. It bespoke utility as well. It made possible the bringing together of germ plasms from plants growing far apart, thus insuring virile and variant strains; and this determined in large measure the amount and direction of the evolution of the highest orders of plants.

For it must be observed that, with rare exceptions, the higher plants are precisely those that long ago entered into this cooperative scheme whereby they trusted their fate absolutely to the insects. They hazarded much—for if anything should lead to the destruction of a few insect races, entire orders of plants would have become extinct. But if they risked much, they also profited much; for the cross-pollenizing effected by the insects afforded the constant stimulus to

variation that underlies all evolution, and enabled the plants that entered into the coalition presently to outstrip their fellows.

Wherever you find a tribe of plants that shows great diversity of form, large numbers of species, and ready adaptability to improvement, you will as a rule find a tribe of so-called "entomophilous," or insect-loving flowers, dependent upon the winged messengers for the consummation of their matings.

Vast responsibilities then were implied in this coalition of the plants and the insects; but the results have justified the hazard.

Plants That Did Not Join the Union

We shall presently see illustrated in detail the curious adaptations of form and color and structure to which the plants of various species were led in their rivalry to secure the good graces of the insects and thus to make sure of perpetuating their species.

Every blossom of the entire orchard, every flower of the garden, and with a few exceptions all of the vegetables under cultivation furnish illustrations in point. But it should be recalled that there are large numbers of plants of a lower order that from the outset refused to enter into the coalition, and that even to this day have

declared themselves independent of the plant-insect union.

Parts of this nonunion clan are the entire races of lowly mosses and lichens; a goodly number of aquatic forms that maintain the appearance and manner of their remote ancestors; and the familiar tribe of ferns; and the trees which depend mainly upon the wind.

Of these, the ferns, mosses, and other forms less familiar to the amateur, have obstinately retained throughout the ages the primeval habit of propagating their kind, not with immobile pollen grains, but with the aid of self-moving germ cells. These motile germ cells, of microscopic size, find their way through the water—supplied in case of land plants by a film of rain or of dew—from one plant to another, and effect cross-fertilization without calling in the aid of any allies. They do not need to attract insects, and so they have not adopted the system of advertising through the development of large and showy blossoms and nectar cups to which the members of the plant-insect alliance are obliged to resort. But if the lowly plants thus maintained their independence, they have done so at a very great sacrifice.

They are not more independent than they are unprogressive; and indeed they are unprogres-

SEED-BEARING PUMPKIN BLOSSOM

This blossom is the mate of the one next preceding. The stigma to receive the pollen occupies the same position that is occupied by the pollen-bearer in the other flower. The bulbous growth at the base of the flower is the ovary, or seed case, which, if the flower is fertilized, will develop into a pumpkin.

sive precisely because of their independence. The method of cross-fertilization that they have adopted does indeed enable some of them to blend the strains of different individual plants; but in every instance the parents must be growing in the immediate vicinity of each other.

Except by the accidental and most unusual transfer of a plant through the agency of a passing animal, there is hardly the remotest chance of effecting cross-fertilization between individual mosses or lichens or ferns growing in widely separated regions.

But we have already seen that it is precisely this blending of traits brought from parents growing under different environing conditions that is chiefly responsible for making plants vary and furnishing the materials for evolutionary progress. So it goes without saying that the plants that are restricted in the choice of possible mates to individuals growing under the same conditions to which they themselves are subjected, cannot expect to change rapidly and therefore do not evolve in any such ratio as plants having the other habit.

And in point of fact we find that the plants that retain this primitive custom of fertilization with the aid of motile germ cells, acting quite independently of insect or wind, are plants of a

low order of development, showing relatively little diversity of form and small capacity for adaptation.

The most conspicuous of them with which the ordinary observer is familiar, namely, the ferns bear a striking resemblance in contour to plants of the remote Carboniferous Era, traces of which have been preserved in the coal beds. And there can be no doubt that this persistence of the primitive form has been largely due to the special method of fertilization which the ferns have retained.

If it be permitted to carry personification one stage farther, we might say that the ancestors of the ferns belonged to a conservative family, jealous of its independence, and unwilling to enter into outside alliances.

And the penalty of conservatism here, as so often in the range of human experience, has been racial stasis.

Plants That Have Left the Union

It would appear, however, that there are certain races of plants that were once members of the plant-insect alliance but which are now no longer in the union.

These apostates include two quite different tribes of plants.

On one hand there are numerous gigantic trees that no longer depend upon insects for the fertilization of their flowers.

On the other hand there are little cowering plant waifs that nestle close to the earth and which, in quite a different manner, also assert their independence.

The trees that have thus revoked the treaty of alliance include such familiar forms as the pine, the oak, and the walnut.

These trees, and a goodly number of their fellows, long ago declared against further co-operation with the insect, and adopted the method of producing large quantities of pollen and scattering it in the air to be carried by the wind to the pistillate flowers, which in some cases grow on neighboring branches and in other cases on quite different trees.

The method is in one sense wasteful, inasmuch as it involves the production of vast quantities of pollen, only an infinitesimal portion of which will ever come in contact with a receptive pistil. And of course the production of this pollen must draw heavily on the energies of the living substance of the tree.

But, on the other hand, the tree that thus depends upon the wind rather than upon the insects is under no necessity to develop large and

A POLLEN-BEARING GRAPEVINE

Plants of the grape differ as to the character of their flowers. Some have almost perfect blossoms; others are staminate, or, at most, have only a rudimentary ovary. The grape thus occupies an intermediate position between those plants that always bear perfect flowers and those that always bear the stamens and pistils on separate blossoms. The various arrangements suggest the need of cross-fertilization in the economy of plant life.

conspicuously colored flowers. Nor need it produce nectar to feed the insect allies, since these have been renounced. And it may very well chance that the saving of energy thus effected more than counterbalances the waste through excessive pollen production.

At all events the plants that have adopted this system of pollinizing give evidence that their plan is not a bad one in the very fact of their extreme abundance.

Moreover the "wind-loving" or "anemophilous" plants, as the botanist terms them, have not only produced a great variety of species and vast numbers of individuals, making up the bulk of our forests, but the individuals themselves are of such virility of constitution as to attain gigantic size. Indeed a moment's consideration makes it clear that the plants that had depended on the wind rather than on insects for fertilization are quite in a class by themselves in the matter of size, inasmuch as they constitute the bulk of our temperate forest trees.

This relation between size and habit of spreading the pollen broadcast on the winds cannot be altogether accidental.

But whether the trees grew large because they had given up the alliance with the insects, or whether they gave up the alliance because

they were growing large, it would be hard to say.

We know that, in the main, insects tend to keep near the surface of the earth, and it may be that the plants that tended to grow very tall were relatively neglected by the insect messengers. But, on the other hand, there are insects that haunt the highest trees, and we can hardly doubt that had even the tallest of plants desired to obtain the services of insect messengers, races of these would have been developed that would have proved equal to the most exacting demands.

What seems on the whole most probable, then, is that the trees have adopted their method because of the very nature of the conditions under which they grew.

By raising their heads high and higher into the air they obviously put themselves more in contact with the wind and thus make it increasingly possible to spread their pollen broadcast across wide stretches of territory.

As a matter of fact we know that the pollen of pine trees in particular may be carried almost in clouds for scores and even hundreds of miles.

So there is every opportunity for the cross-fertilization of individual trees growing in widely separated territories; and there is therefore no restriction put upon the possibilities of progress

and evolution for these large-growing plants in penalty for their renunciation of the services of insect messengers.

The case of the trees, then, simply illustrates the fact that there may be more than one way to effect a given purpose, and that a change of method may be no barrier to progress, even though the abandoned method still remains an admirable one for a vast coterie of organisms of slightly different habit.

Self-Fertilized Plants

But the case of the other company of plants that have backslidden from the insect alliance is altogether different.

The plants in question do not make up any great conspicuous tribe comparable to the forest trees, but are a miscellaneous company of lowly vegetables of unrelated families. Familiar examples are the wheat of the fields, peas and beans in our garden, and a certain number of the more obscure species of violets.

The jewel weed, the fennel, the rue, and the nettle are other somewhat less familiar yet not uncommon tribes of plants whose flowers are habitually self-fertilized.

There can be no question that these plants are the descendants of tribes that were at one time

members of the plant-insect union. The fact that most of them retain more or less conspicuous flowers proves this beyond question. In the case of the wheat, which might be thought a possible exception, there is the evidence of certain species of wild wheat, growing to this day in Palestine, which have only partially renounced allegiance to the insects, still putting forth flowers that on occasion may be cross-fertilized with their aid or with that of the wind.

Just why these various plants of different families have departed from the custom that has served their fellows so well, would be interesting matter for conjecture.

Yet that wheat should make this change is no doubt because it has under cultivation been grown *en masse,* giving it no opportunity for individualization. The most plausible suggestion is that the ancestors of the plants that now have closed flowers and thus depend exclusively upon self-fertilization had fallen upon evil days in which there was a dearth of insect messengers in the regions they inhabited.

The story of the starved martins, told in an earlier chapter, furnishes a striking illustration of the fact that insects that ordinarily are abundant may in any given season fail to make their appearance.

And even if the insects themselves are abundant, the weather conditions, in a given season, may be such as to make it almost impossible for them to carry out their bargain by transferring pollen from flower to flower. Every orchardist knows that a protracted rainfall just at the time when his apple, pear or plum trees are in bloom may prevent the bees from visiting the flowers; and in such case, as is only too well known, there will be a partial, or no crop that season.

With trees and other perennial plants it is not a matter of absolutely vital importance that there should be a crop of seeds produced each season.

Failing progeny this year, next year or the year after will answer in the case of a plant which grows on a permanent stalk or from roots which outlast the winter.

But the case of the annual plant is altogether different.

Should such a plant fail for a single season to produce seed, its entire race might vanish instantly from the earth.

That thought is rather startling when presented thus tangibly.

Yet its truth is almost axiomatic. Quite often the entire seed crop of an annual plant in a state of nature germinates or decays the ensuing

STRAWBERRY BLOSSOM
(*Enlarged*)

Some varieties of strawberries bear perfect flowers, as illustrated in this specimen, and others have blossoms that bear the pistils separately. It is necessary, in cultivating the strawberry, to bear this in mind, and if a pistillate variety is planted, there must be pollen bearers in the neighboring rows, otherwise there will be no crop of berries. The bees are depended on to effect the transfer of pollen. In these perfect flowers the stamens and pistils mature at different periods, to guard against self-fertilization.

season after its production. And it is absolutely incumbent on the plants that grow from this seed to produce in turn an annual crop of seed that will carry on the racial stock.

So it is not strange that a plant that is thus perennially threatened with destruction should adopt exceptional measures to insure the fertilization of its flowers.

Very often it may have happened that certain individual flowers that chanced to be self-fertilized were instrumental in saving the life of a species that otherwise would have been exterminated. And as, through the operation of heredity, the offspring of these flowers would tend to reproduce the self-fertilizing habit of their parent, the surviving representatives of the species might thus come to constitute a tribe in which the habit of bearing self-fertilized flowers was the prevailing custom.

And thus it is, perhaps, that the method of reproduction followed by the wheat in our fields and the peas and beans in our gardens may be accounted for.

Yet the fact that certain of these self-fertilized flowers, as for example the violet, retain the custom of putting forth showy flowers even though these for the most part are seedless, shows how powerful is the hold of remoter heredity,

THE STIGMATIC SURFACE OF A POPPY MUCH ENLARGED

The stigma of the flower may be variously modified to facilitate reception of the pollen. This picture shows the curious arrangement in the case of a poppy. The pollen grains deposited on this stigmatic surface send out little tubes that penetrate the stigma and ultimately make their way to the ovule or seed case, carrying the nucleus that unites with the nucleus of the egg cell, thus effecting fertilization. Each egg cell is fertilized by a single pollen nucleus.

It may well be doubted whether the existing races of cultivated wheat could perpetuate their kind, if put upon their own resources in competition with wild plants, for a dozen or two dozen years.

The habit of self-fertilization may preserve for a certain number of generations a plant that would otherwise have been completely exterminated; but at best it marks a stage of degeneration and decline. The plant that follows it is in a sense retracing its steps down the ladder of evolution by which its ancestors have made ascent.

And so it is not surprising to find that the vast majority of the useful plants of orchard and garden have kept up the traditional alliance with the insects to which they owe the multiplicity of their specific forms and the virility and adaptability of the individual members of their organization.

The Wisest of Plants

It is flowers of the great brotherhood of insect lovers, then, that chiefly claim the attention of the plant experimenter, because these are the ones that make up the chief census of orchard and garden.

As a matter of course it is plants of this fraternity that are of interest to the amateur,

because, generally speaking, it is these alone that put forth blossoms that please the eye.

Whoever is interested to undertake experiments in plant breeding must, then, familiarize himself with the mechanisms by which the plant makes known its appeal to the insect and those through which the perpetuation of its kind is effected; the mechanisms, that is to say, of the typical flower.

As we come to study flowers in detail, it will appear that among those dependent upon insect fertilizers, no less than among the wind-fertilized, there are individuals that bear the essential organs of the flower in separate blossoms. Reference was made to this in the case of our crossing experiment with a certain species of dewberry, and we shall see other illustrations of it from time to time.

But the major part of the most familiar cultivated plants, including all the conspicuous fruit trees of our orchards, bear flowers each of which contains within the same blossoms both the staminate and the pistillate organs.

Ordinarily it is the function of the bee to carry pollen from one blossom to the pistil of another. But on occasion even these flowers may be self-fertilized. Thus it may be said that the most important, from a human standpoint,

among the existing plants have adopted a compromise in which cross-fertilization is the rule, yet which makes possible self-fertilization in case, under the stress of circumstances, cross-fertilization should fail to take place.

Doubtless, on the whole, this was the best course of all. The plants that adopted it might be said to be the wisest of their kind.

The Typical Flower

What may be regarded as the typical or perfect flower, then, is one that contains both pollen-bearing and pollen-receiving parts, surrounded by the conspicuous insect signal that we term the corolla; and having also a less conspicuous outer shield termed a calyx.

The calyx is the original shield about the flower bud, and its function is over when the flower opens.

The botanist ordinarily speaks of the calyx as modified leaves. He refers to the petals of the corolla as being also modified leaves or enlarged and beautified modifications of the calyx. He thinks of the stamens and the pistil as modified petals; and he justifies this estimate by showing that under cultivation it is often possible to transform these essential organs into petals.

Thus, for example, are produced such double flowers as the cultivated rose, dahlia, and the chrysanthemum. To the human eye, these are things of beauty but from the standpoint of plant economy they must be regarded as travesties of flowers, since they are far less able and often wholly incapable of producing seed.

But it is perhaps a somewhat more philosophical view of the flower to consider it as a mechanism developed about the all-essential central organ, the pistil.

This, the female organ of the plant, consists, in the developed form, of a basal structure, the ovary, containing the ovules or embryo seeds, and a more or less protuberant style at the end of which is the stigma that receives the fertilizing pollen.

Considered as to its origin, the pistil is in effect a modified bud. Everyone is aware that individual buds of a plant may have the property of being able to reproduce the entire plant. The pistil is a modified bud each embryo seed of which, when fertilized, has the same potentiality.

By the most wonderful miracle of the organic world, this infinitesimal structure is enabled to epitomize all the possibilities of a future plant, of predetermined size and form and habit.

It differs from the bud from which it is developed chiefly in that it requires to be fertilized by union with a pollen cell, before it is capable of taking on development; and in the further very essential fact that when mature it may be cast off from its original moorings and carried to any distance, thus in a way making amends for the limitations put upon vegetables by their incapacity for locomotion.

The stamens that normally grow in a circle about the central pistil develop at their ends anthers that produce, usually in relatively large quantities, pollen grains of exceedingly minute size. And each pollen grain contains, somewhat as does each ovule, all the hereditary potentialities of the entire plant. The pollen grain cannot, indeed, be made to develop into a plant; but its union with the ovule is essential to the development of that organism, and it is certain that the pollen grain, despite its infinitesimal size, brings to the union factors that represent its parent plant effectively and in full measure.

It would be unbelievable, if we did not know it to be true, that a fleck of matter of scarcely more than microscopic size should contain the potentialities of a mammoth tree, and should predetermine the details of structure of a future tree even to its remotest leaf and to the finest

details of its flowers and fruit. But that the pollen grain actually has these potentialities has been demonstrated thousands of times over by the plant experimenter.

Any amateur who wishes to test the matter may do so, to his complete satisfaction, by making the simplest experiment in cross-pollenizing and watching the growth of the hybrid seedlings his work brings forth.

The pollen grain effects union with the ovule by sending out a threadlike filament of protoplasm, like a tiny root, which penetrates the stigmatic surface, passes down along through the style, and carries the nucleus of the pollen grain to the nucleus of an ovule. When the two nuclei come in contact, fertilization has been accomplished.

When pistil and the stamens have been considered, we are through with the really essential mechanisms of the flower.

From the human standpoint, of course, chief interest centers in the corolla with its widespreading petals of varied colors. To the plant itself this structure is in a sense essential, inasmuch as it supplies the visible signal that attracts the attention of the insect. But beyond this it has no share in the process of fecundation. We shall have occasion to consider the form and structure

of this showy portion of the flower in a multitude of individual cases, and to observe how it may be modified by process of selection, but from the present standpoint it does not call for further consideration.

From the standpoint of the pollenizer, the stamens with their pollen-bearing anthers and the receptive pistil—with or without a stigma at its tip, but always having one or more ovules in the egg case at its base—are the organs that claim exclusive attention.

Hand-Pollenizing

The essence of pollenizing is merely the transfer of pollen from the stamen of one flower to the stigmatic surface at the end or rarely at the side of the pistil of another.

This is the work that is ordinarily accomplished by the insect. It is all that the plant experimenter accomplishes when he wishes to effect the crossing of different plants of the same species or the wider crossing, commonly called hybridizing, of different species.

There is nothing occult in the practice of the bee or in the imitation of his work as practiced by the hand of the pollenizer.

What is accomplished in each case is the purely mechanical transfer of a certain number

of minute pollen grains from one place to another. Beyond that, everything depends on the vital activities of the plant tissues themselves.

We shall have occasion in another chapter to deal somewhat at length with specific methods that are necessary to effect cross-pollenizing in the case of sundry types of flowers that have developed blossoms curiously modified as to form or details of structure. But the general processes of hand-pollenizing, as they apply to the chief flowers of the orchard and garden, may be stated in a few words.

The essential thing is to secure a certain quantity of pollen, usually by shaking it from the flower on a watch crystal or other small receptacle, and to transfer this pollen to the receptive pistil of another flower either with the finger tip — which furnishes in general the most useful piece of apparatus — or with a camel's-hair brush.

It is desirable to cover the receptive portion (stigma) of the pistil fully with pollen, partly to insure complete fertilization, and partly to prevent the vitiation of the experiment through possible subsequent deposits of pollen from another source.

If the flower to be fertilized has stamens of its own, these should be removed before they

RASPBERRY BUSH AFTER POLLINATION

Here small paper bags have been tied loosely over the flowers that have been cross-fertilized. It is not usually necessary to resort to this expedient, for if the stigma of a flower is entirely covered with pollen, there is little danger of subsequent contamination with other pollen, especially if the stamens also have been removed. To make assurance doubly sure, however, the paper bags may be used, particularly by the amateur who operates on a small scale.

are fully ripe—which is often a few hours or a day before the foreign pollen should be applied. This removal of the stamens may usually be done with a pair of small pincers. In case of flowers that have short pistils — the cherry, apple, and other orchard fruits being good examples—the unopened flower bud may be cut around at about the middle with a thin-bladed knife, the anthers being thus excised at a single stroke. With other flowers the mechanical details vary, of course; but the process is sometimes quite complicated and calls for skill and common sense.

So-called composite flowers, however, require special treatment. The daisy and the sunflower are familiar examples. Here the true flowers are very small and grouped in masses. Individual treatment is usually out of the question. The best method is to wash away the pollen with a carefully directed stream of water from a garden hose, or by spurting water from the mouth; after which the head of the pollenizing flower is rubbed against the one selected, thus effecting fertilization *en masse*.

In exceptional cases it may be desirable also to cover the fertilized flower with a paper bag to prevent the visit of insects; but in practicing pollination on a large scale this may usually be

omitted by those who have experience enough to recognize the hybrids from the others.

If the stigma has been satisfactorily covered with pollen, it will present no exposed surface for the reception of other pollen grains.

The rule is simply this: Seek nature's plan and follow it.

In other words, take a lesson from the bees, and pollenize the flowers somewhat as they do. Bear in mind the essentials of the process, which are the same for every flower. Study the mechanism of each new flower and adapt your precise method to the needs of the individual case. It does not matter just *how* the pollen reaches the stigma, provided it *does* reach it.

A very short course of practice will give you the knack of cross-pollenizing, and enable you to enter on a course of experiments that will lead to surprising, fascinating, and perhaps far-reaching results—results which may prove to be in time of world-wide significance.

The ferns belong to a conservative family; and the penalty of conservatism, whether in plants or in human beings, has always been racial stasis.

QUANTITY PRODUCTION

On Seedlings and Their Care

THE word "evolution" chances to have nine letters. Suppose that these letters were penciled on nine blocks of wood that are otherwise identical, and these little blocks were put in a bag and mixed together. Suppose then that you were asked to put your hand in the bag and bring forth one block after another, placing them in sequence as you brought them from the bag.

What probability is there, do you think, that your blindfold selection of the blocks would result in bringing them out in such sequence as to spell the word "evolution"?

A mathematician could doubtless figure out the exact probabilities, but you need not be a mathematician to realize that the chances are almost infinitely against you.

Now, am I not right in saying that the plant developer who expects to find a considerable number—let us say nine—of particular qualities

"FLAT" WITH LAYER OF GRAVEL

A layer of gravel is put at the bottom of the germinating box to facilitate drainage and aeration, both of which are very essential to the proper growth of the plant roots. This is a detail of special importance.

This selected seedling he may nurture and use as part of his equipment for further experiment just as you retained the letter "E" as marking the beginning of your success in spelling the word "evolution."

And as the plant developer continues his experiment with successive crossings and successive selections, he will be able in later generations to find individual seedlings that combine successively more and more of the qualities he is seeking. When, finally, he reaches the stage where the parent forms have between them all the desired qualities in superlative degree, he is somewhat in the position that you were in when only two of your lettered blocks remained in the bag. There is at least an even chance that he will find among his seedlings of the next generation one that will approximate his ideal, even though the number from which he selects is far smaller than the earlier groups.

Thus by advancing step by step and using the ground gained as a new starting point the experimenter attains his end with comparative celerity, even though there would have been scarcely more chance of attaining that end with a single experiment than you would have had of spelling out the word "evolution" at a single series.

"FLAT" PARTLY FILLED WITH PREPARED COMPOST

The "flat" is partly filled, on top of the layer of gravel, with specially prepared soil, which is then tamped down with a board, making a flat surface on which the seeds are sown. The seeds are covered to about twice their diameter with light, sifted compost.

Take by way of illustration the case of our stoneless plum. We discover soon that the stone seed is prepotent or dominant, and stonelessness latent or recessive. So we must be prepared to see the progeny of our first generation of hybrids all produce common stony fruit. But a knowledge of the tendency of latent or recessive characters to reappear in successive generations comes to our aid, and we go on with the experiment with full confidence, even though for the moment we seem to be going backward rather than forward.

In due course the second generation of plums appears with a number of stoneless specimens, the latent character having come to the surface. But these lack many of the good qualities that our perfected fruit must have, and in order to breed these qualities into the stock we must make a new cross; and this will involve the breeding in again of the tendency to bear stone fruit.

So in three generations we shall find ourselves, as regards the essential quality of the stony seed, somewhat further back than we were in the beginning.

But, on the other hand, our third generation fruit, even though it has a stony seed, has qualities of flesh that its stoneless ancestor altogether lacked; and in the fourth generation we shall be

prepared to find individual seedlings that bear stoneless fruit of greatly improved quality.

In each successive generation, then, we are dealing with better material—getting the chances grouped, if you will.

Winning Against Odds

But, in a sense, we are running counter to the trend of heredity, because the vastly greater proportion of the ancestors of our plum were bearers of stoned fruits. And so we must continue reshuffling and dealing over, as it were, and watching results. We may lose in one generation what we gained in the generation before as regards the matter of stonelessness; even while on the whole advancing toward the production of a fruit of desired quality.

But just in proportion as our ideal calls for the combination of numerous good qualities, does the attainment of that ideal become difficult.

Even when, at let us say the fifth or sixth generation, we interbreed individuals that have the desired quality of stonelessness, we shall not at once secure what is desired; because our seedlings combine so many ancestral traits that they will not breed true. Even though they are all stoneless there will be a great variation as to other qualities, and it is only by dealing with

large numbers of seedlings that we can hope to find one or two that will show the desired combination of traits in high degree.

And the lesson which should be preeminently inculcated is this: You must make many experiments at plant breeding before you can hope to secure the final combination—the sequence of qualities—that you desire.

The Logic of Quantity Production

Now note the application: Each individual seedling of a hybrid strain represents a unique combination of ancestral traits, and constitutes in itself a new and unique experiment—equivalent to an independent deal of the cards. So the probability of securing what we seek will be somewhat proportionate to the number of seedlings.

This is particularly true in the case of such variable plants as the fruit trees of our orchards. The case is far simpler when we are dealing with plants that vary little in their qualities, or where we are breeding with only a single pair or two pairs of unit qualities in mind—say "hardness" of kernel and immunity to rust, as in Professor Biffin's experiments with wheat; or good flavor and whiteness as in the white blackberry.

But where the varied traits sought to be combined in a Shasta daisy are in question; or the

many qualities of a commercial cherry or prune, the case assumes new complexities.

Hence it is that my records tell of tests applied to about half a million seedlings of the daisy; seven and one-half million seedlings of various plums, and the like.

Hence also the constant necessity of what my neighbors speak of as ten-thousand-dollar bonfires in my orchard, when we burn seedlings that have been inspected and found wanting. To burn 65,000 hybrid blackberries in one pile, as I once did after saving perhaps half a dozen individual plants for further testing, seems like willful extravagance to the casual observer, but it is an unavoidable incident in the search for perfect fruits.

Such prodigal use of material implies a large measure of experience in the handling of seeds and the growing of seedlings. In point of fact, it might be said that this is the most important part of a plant breeder's task, so far as the practicalities of experiment are concerned. It is part and parcel of his daily routine.

It is highly desirable, then, that the would-be experimenter should gain a clear understanding of the essentials of method of caring for seeds and cultivating seedlings. So it is the purpose in the succeeding pages of this chapter to give a

few practical hints as to various aspects of the subject. Thus summarized, the lessons learned in the hard school of experience may enable the reader to avoid some pitfalls and to make certain experimental short cuts.

Keeping Seeds Over Winter

To begin at the beginning, let us note that the preservation of seeds over winter calls for careful attention.

All fruit seeds except those of apricots and almonds, when removed from the fruit, are at once placed in slightly moist, coarse sand or fine gravel or in sterilized sawdust.

In warm climates the boxes containing the seeds are then buried on the shady side of a building or tree where they will become neither too dry nor too wet. The object is to keep the kernels as nearly as possible in their original condition.

If tree seeds, especially those of the cherry, the pear, and the plum once become thoroughly dry, it is difficult, and in some cases impossible, to induce them to germinate. An important function of the pulp of these fruits, in the original wild state, was, presumably, to keep the seeds moist until the season for germination.

I have elsewhere called attention to the exceptional difficulty of keeping stoneless plums and prune seeds in condition for growing. Not having the natural protection of the shell, they tend to germinate too early, and of course are peculiarly subject to the attacks of insects and of fungous diseases. Such seeds may best be placed in cold storage as soon as collected and cleaned, and kept at freezing temperature. Seeds thus cared for will sometimes germinate almost as quickly and readily as beans or corn. They must not be planted too early in the spring, lest their too prompt germination subject them to injury from late frost.

Incidentally, I may note that grafts sent to me from cold climates have been observed to start with greater promptness and grow better than those from our own immediate vicinity where the winters are mild. Cold seems to rest the tissues and prepare them for rapid growth, just as treatment with narcotic drugs has been observed to do in certain interesting experiments that will elsewhere be referred to more at length.

Out of Door Planting

In California, plum seeds are usually planted in January or February, in a little furrow about an inch deep. A furrow may be made accurately

and expeditiously with the aid of a triangular bit of board an inch or so wide nailed across another longer piece, so that when drawn along a garden line it makes a narrow furrow of exact width and uniform depth throughout.

Plant the seeds about one-half inch to an inch apart, and cover with a thin layer of soil; then fill the furrow with sawdust. This is an important matter with cherry and plum seeds, especially with the stoneless ones which must be given every inducement to push through the soil. A heavy, compact soil placed over cherry and plum pits prevents a large number from pushing up to the light. For this reason a sawdust covering is preferred, and it also regulates the moisture with exactness, allows for sufficient aeration, and equalizes the temperature. Moreover, the sawdust is distasteful to slugs, thrips, cutworms, and other insect pests.

Peach, nectarine, and apricot seeds are planted farther apart and a little deeper; quince, pear and apple seeds are planted about the same as plum seeds, both as to distance and depth, or in large lots may be rather thickly sown in drills or furrows six or eight inches wide and eighteen to thirty inches apart.

For growing seedlings of conifers—pines and their allies—cold frames or shallow boxes are

A COLD FRAME

To accustom seedlings to the outdoor air, they are placed in inclosures covered with movable frames made of laths, which shield the tender seedlings partially from the wind and sun until they are hardened and ready for the fields.

used filled with mellow sandy loam; or the seed may be sown broadcast or in rows in cold frames without boxes. The object of the cold frames is to shelter from hot sun and drying winds and in cold climates to prevent freezing.

If the season is short or if warm weather comes on suddenly, it is sometimes desirable to soak seeds in water before planting.

After being in the water several hours they should be drained and set in a warm place where germination can start quickly. In this way growth may sometimes be advanced by a week or more. But such forced germination is not usually necessary or desirable. If carried too far before planting, it endangers the growth. On the other hand, the very early plants often escape cutworms and other insects by attaining a fair growth before these pests make their appearance.

Boxes for Seedlings

Valuable plants to be grown in large quantities from rare seeds, may best be started in small boxes or "flats" indoors, under glass or in sheds made of laths or slats so spaced as to allow free entrance to air and sunshine.

Boxes of the right design and construction are far better for this purpose than pots or earthen pans. The boxes or "flats" that I have used

for forty years are made of redwood lumber. Where this cannot be obtained, cypress is nearly as good, but soft pine is not durable and should be avoided. Eighteen inches square, outside measure, four and one-half inches deep, inside measure, is a good size.

Two opposite sides are of common board lumber three-quarters or seven-eighths of an inch thick; the other sides are a little less than half an inch thick. The bottoms are made of redwood "shakes" which are about one-fourth of an inch thick; two or more spaces of an eighth of an inch being left for drainage. Across the bottoms are nailed three strips which add rigidity and strength as well as affording better ventilation and drainage. After all the parts are carefully fitted, the joints are sometimes dipped in linseed oil before being strongly nailed together. This gives durability and tends to prevent the nails from rusting out.

These redwood boxes may be used for many years if sterilized once a year by being placed for about three or four minutes in boiling water.

A suitable soil is the first requisite in raising seedlings in boxes. The mixture which I have generally found best for use in the early winter for raising seedlings in boxes in the greenhouse, is compounded about as follows: One-half clean,

rather coarse, sharp sand; with about 40 per cent of some good pasture or forest soil which generally contains more or less leaf mold. To this is often added 10 per cent finely powdered moss or peat. These mixtures, with the addition of about one or two per cent of fine ground bone meal or superphosphate, make soils in which seeds of almost any kind of plant from any part of the earth will germinate. Seedlings thrive in this soil until they are ready for transplanting.

If seeds of choice plants are to be grown, the soil is sterilized by a thorough scalding to destroy any fungus or insect pests.

Usually we find it suits the plants better if a part of the soil last prepared is left over for use with the new mixture, like yeast for a loaf of bread, and I always prefer to have a little of the old on hand for this purpose.

Common sharp sand, if the right texture can be obtained, is far better for cuttings than the soil just described. The sand found along creek or river banks is generally free from injurious insects or fungous diseases. But for rare cuttings and very choice seeds, this should be rinsed by pouring large quantities of water through it, at the same time stirring or jarring the material.

In filling the boxes, coarse gravel, such as will just pass through a half-inch mesh, or a little smaller, is placed one-quarter to one-half inch deep over the bottom of the box. This insures perfect drainage and sufficient *aeration,* both of which are of the utmost importance. The box is then filled, to within about an inch of the top, with the sand or special soil. Make the filling a little shallower for fall planting, when we expect much cool, damp weather, and slow growth, to prevent drowning or "damping off" of the seedlings during the winter; a little deeper for spring planting, to prevent too sudden drying out, and otherwise to regulate the amount of moisture.

This may seem like a matter of small consequence, but such details often determine success or failure.

The Seedling Kindergarten

All ordinary seeds are sown quite thickly in the boxes and covered lightly with the same soil, according to the size of the seed—just a dusting of soil for the finest of seeds, and an eighth to a quarter of an inch for the larger ones.

In testing new varieties, ten or twenty different kinds of seeds may be planted in sections in one box, each marked with a small wooden label, tacked on the upper edge of the box with

the name, or the reference-book number, of the seeds. After the seeds are planted, the surface is pressed down with a flat piece of board until it is level, smooth, and solid.

Instead of watering the surface by any sprinkling process from above, the boxes are placed, after the seeds are planted, into a square pan containing water sufficient in depth to rise nearly or quite even with the surface of the soil. In a few minutes the water saturates the soil and entire contents of the box, without disturbing the seed, and without packing the soil in the least. The boxes are then removed and tilted to one side so that the superfluous water can slowly drain out.

A thin layer of our Western green tree moss sifted over and under the seeds acts as a non-conducting blanket, equalizing the temperature and retaining moisture. Sphagnum moss is not nearly as good, for it makes an almost impervious paperlike covering after being wet, yet if rather finely ground when dry, it is better than none.

A thin layer of moss on the surface protects the seeds or young plants from being washed about when they are watered from above, as they are usually sprinkled after a few weeks of growth. The thin covering of moss also wards off some of the fungous diseases which afflict tender seedlings. All this may seem like unnecessary trouble,

PROTECTING SEEDLINGS FROM THE BIRDS

A net drawn over the young plants in the propagating beds gives protection from the birds, and is an indispensable auxiliary where rare exotics or new hybrid varieties are being raised.

letting them drain a little before attempting to transplant. Then with a trowel they may be taken up with the dirt surrounding the roots and set out.

After marking the rows with a garden line, a long narrow crevice is cut by inserting a flat spade and moving the handle back and forth a few inches. The plants can be rapidly placed in the crevice thus made. One side of the soil is pressed down with the foot or with a tamper, and packed quite firmly against the roots.

Then more soil is drawn in with a hoe or rake and carefully placed about each plant, after which a common garden rake is used in leveling and loosening up the soil along each side of the row, which prevents "baking" and helps to keep the temperature equable and the soil moist. The most tender plants treated in this way are saved almost without exception.

Out in the Open

Nearly all plants should be set out in the field somewhat deeper than they grow in the boxes. When plants have long roots these should be straightened out and placed as deeply as possible in the soil to give them a good start by the time the dry summer weather commences. Otherwise the young plants could not, in some cases, extend

their roots fast enough to keep up with the gradually disappearing moisture, and so might die of thirst.

When seedlings are removed from the protection of the glass house to the open air, or in transplanting in the fields, it is best, if possible, to choose a time when there are no severe winds, and when the sun is not too hot and the atmosphere neither too dry nor too chilly.

Generally in California tender plants best withstand moving from the greenhouse to the open air just before or during a warm rain. At such times the atmosphere is similar to that in the greenhouse. Even under the most favorable circumstances they must be shielded from winds or bright sunlight to which they are not adapted.

To accustom the tender seedlings to outdoor conditions, the flats are placed in square frames about six feet wide and a foot or two high. These are covered with a portable covering made of common laths nailed on narrow strips of board, so placed that the space between the laths is about equal to the width of a single lath.

When the boxes of plants are placed in these frames, it is best to have some slats underneath so they will not rest on the ground; otherwise fungous diseases are often communicated from

the earth to the soil in the boxes and to the tender plants.

When the slat covering is kept over the frames for five to twenty days, according to the season, the little plants will have adjusted themselves to their new environment so that the slats can be removed.

After a few more days of growth they will probably be strong enough to be removed to the open ground.

Running the Gauntlet

Many tiny seeds, just as they are germinating, may be destroyed in a short time by a cold dry wind, or they may be killed even more quickly by too much moisture and too little air.

Young seedlings may be killed by a common fungus which causes "damping off." This is very destructive where plants are grown too thickly in the seed boxes especially in a close atmosphere before transplanting. Sometimes a whole box containing thousands of valued seedlings will be destroyed in this way in a few hours, the trouble generally commencing in little spots or patches from which it rapidily spreads in all directions.

The tiny plants may most often be saved after the fungus starts by applying a dusting of sul-

YOUNG PLANTS AWAITING SELECTION

The very first step in selection comes with the tiny seedlings showing their heads above the ground. At their first appearance it is often possible to judge many of the characteristics of the plant and its fruit which, later, become confused as the battle of warring heredities grows more acute. Much of this work of selection is done from tiny seedlings in the flats before removing from the greenhouse.

phur or of coarse, dry sand or gravel. Sometimes if placed in a cool, dry atmosphere so that the excess of moisture is evaporated they may be saved.

Dry sand or fine gravel sprinkled over the moss when the seeds are planted is the first and best preventive of damping off. It covers the soil with a substance on which the fungus cannot readily establish itself, and thus separates the unhealthy from the healthy plants. If good care in general is supplemented by the use of this dry sand or gravel, the fungus has little chance to spread from plant to plant.

Of course, one is obliged to be on the lookout for insect pests, slugs, cutworms, crickets, aphides, and thrip, which are sometimes very destructive. Slugs, cutworms, and crickets require instant attention when they first attack the young plants. The appetites of these pests often increase to greater proportions than can be appeased by the growth of the remaining plants and they must be carefully sought in or under the boxes.

Sometimes slugs may be headed off for a time by sprinkling lime, red pepper, quassia, or tobacco dust in their paths. Thrip and the aphides are best destroyed by fumigating the houses once a week or twice a month with tobacco smoke; the

frequency may be regulated according to the abundance and the persistence of the enemy.

All in all, it is a severe gauntlet that the little seedling is called upon to pass. Yet if the methods described in this chapter are carefully followed out, it is possible to grow successfully any seed, from whatever climate or soil or location, that has the least germ of life within it.

These methods have been successfully used with the seeds I am constantly receiving from numerous collectors in Siberia, Brazil, Chile, Argentina, Patagonia, Mexico, Central America, the Philippine Islands, Alaska, British Columbia, north and south Africa, Europe, India, South Sea Islands, Australia, New Zealand, central and western China, Japan, and Korea.

By sedulous attention to the details above outlined, the raising of seedlings becomes so certain a procedure that the loss should not exceed one plant in a thousand. And this, obviously, is a most important consideration, especially with rare foreign seeds or seeds produced by hybridizing experiments that have involved exceptional care and labor. To such priceless stock, any amount of time and labor may be given ungrudgingly. And even in planting common nursery stock one soon learns that a thorough knowledge of the requirements of the plants is essential to success.

GRAFTING AND BUDDING

Short Cuts to Quick Tests

NOWADAYS we hear of some remarkable experiments in the grafting of animal tissues, which strongly appeal in certain respects to those who have long experimented in the grafting of vegetable tissues.

The experiments made by Dr. Alexis Carrel, of the Rockefeller Institute in New York, are of particular interest. It appears that Dr. Carrel has devised a new method of suturing arteries. With such a process, the plant experimenter of course has no concern, for the vital juices of plants are not transmitted in any such definite channels as the arteries and veins of animals. But in dealing with animal life the arteries are all essential, and the process devised by Dr. Carrel enabled him to perform grafting experiments such as no physiologist or surgeon had heretofore found feasible.

All this is so fully in keeping with the familiar experience of the plant experimenter that it had

no peculiar interest for me. Perhaps it seemed less wonderful than it really is because my conception of the fundamental unity of plant and animal life makes it appear inherently plausible that such transplantation of members should take place under proper surgical conditions.

The only difference is that the method of grafting plant tissues one upon another has long been familiar, whereas no one knew just how such grafting could be accomplished in the case of the animal until Dr. Carrel found the way.

We have already seen how the experiments of Dr. Nuttall, of Cambridge University, demonstrated that the quality of *felineness* or *canineness,* so to speak, penetrates to the last drop of the blood; so it is not surprising to find from this independent source that the same characteristic differences extend to the solid tissues.

And of course we are at once reminded of the similarity of experiences of the grafter of plants. Here also there are sharp limits fixed to the feasibility of the grafting method. You may transfer the twig of an apple to the limb of another apple tree, however widely different, with success. You may similarly, although with far less prospect of success, make a graft between twigs of the apple and the pear. In the same way you may combine branches of the different members of the

family of stone fruits—plum with apricot, peach with almond, and the like. But if you attempt to ignore the larger barriers, and strive to graft seed fruit upon stone fruit—apple or pear on plum or peach—your effort will result in failure, just as Dr. Carrel's experiments resulted in failure when he attempted to transpose the organs of cat and dog.

At all events, we are commonly able to make such grafts as we choose between different species of the same plant genus; and we may reasonably infer that the same thing might be possible in the case of animals.

It has been found in plant life where there has been much crossing either naturally or by intent in the past that most striking *individual* differences appear. Some individual seedlings among any lot of such crossbred plants (all of which may have come from the seeds of a single variety) will thrive when grafted on certain other species or varieties *even better* than on their *own* roots, while other individual varieties refuse to combine or grow under any conditions; for instances, the common French prune thrives better on almond roots than on its own, the golden drop plum will not live when grafted on the peach, while some of its nearest relatives, the common French prune and others, grow, thrive, and pro-

COMPLETE GRAFTING OUTFIT

The saw, knives, and pruning shears are self-explanatory. The iron tool with curved handle lying in the foreground is a wedge to prepare a branch for cleft grafting. The utensil at the left is a heater with a basin of grafting-wax with an outer basin of water, and a brush for applying the wax. The tree stump has been cleft-grafted with six cions.

duce fruit abundantly. It thus appears that artificially produced varieties may acquire really specific differences of a profound nature.

The Mutual Influence of Cion and Stock

Leaving the solution of this problem to the physiologist, however, let us turn to the specific task in hand, and consider that very important part of the plant experimenter's task that has to do with the grafting of vegetable tissues.

It is convenient to recall that the trunk or branch upon which a twig is grafted is called the stock, and that the transplanted twig itself is spoken of as the cion. The practical methods of grafting, as applied to different varieties of plants, will be detailed in a moment. But first we may consider very briefly the mutual influence that cion and stock exert upon each other.

That there is an intimate chemical and vital relation between the immediate living surfaces of stock and cion admits of no question. The very fact that we cannot cause plant tissues to make union unless they are of allied species, is in itself sufficient proof of this. Moreover, the fact that the cion must receive its entire supply of water, conveying all nourishment except carbon (which is drawn from the air) through the medium of the tissues of the stock, suggests that there must

be a uniformity of chemical composition between the two that might be supposed to amount almost to identity; particularly after the cion has been in place for a term of years, and has grown from a tiny twig to a large branch or a complete tree.

Yet, in point of fact, there is abundant evidence that the cion maintains its original identity of character from first to last. This may be more readily understood when we know that *all plant food is developed within the foliage.* To be sure the roots supply water, the universal solvent and transportation agent of all life, and small quantities of certain minerals and organic substances in solution, but these are not digested for assimilation as plant food until combined with carbon dioxide which is transformed in the leaf cells under the influence of the active rays of light, first into fruit sugars and by later transformation to cane sugar but oftener to starch, a more stable form of food substance, in which form it is most commonly stored in seeds, bulbs, tubers or enlarged roots or stems, or to wood and less often to various other substances used in the economy of plant life and quite often useful to animal life and to the industrial life of man. These transformations are presented to us in the various food products and the numerous gums, rubber, coloring materials, drugs, oils, and perfumes.

Thus it will be seen that every organic structure on the earth, every plant and animal whether of earth, sea, or air, including man himself, is wholly dependent upon the food always first developed in the leaves of plants.

But to return to our cions—a twig of the Baldwin apple, grafted on a wild crab apple tree, will produce Baldwin apples, and not wild crab apples. Moreover, the Baldwin apples thus grown will be identical in appearance and flavor with those that grow on the tree from which the cion was cut. This seems very mysterious but the like of it is matter of every day observation in the orchard of the up-to-date fruit grower.

Nevertheless, the question has more than once arisen as to whether cion and stock may not exert upon each other an influence of a profoundly modifying character.

That such may be the case, to the extent of producing a poisonous influence, has been observed in the case of grafts between species somewhat distantly related. It has been observed, for example, that some of the English plums unite with the peach, and do fairly well for a time, while others refuse to unite under any circumstances, and still others when budded or grafted on a peach stock seem to poison the

peach tree, even causing its death. Yet, on the other hand, the French prune will grow better on the roots of the almond or the peach than on its own roots.

In each of these cases, it would seem, there must be an influence, in one case harmful, in the other beneficial, transmitted between cion and stock.

It will be observed that such influences as these merely extend to the life or vigor of the plant, and have nothing to do with the question of transferring its inherent characteristics. And it is universally admitted that, as a rule, the influence of stock on cion, or of cion on stock, is thus limited.

But just as you cannot make a dog and cat identical in constitution merely by feeding them the same food, so you cannot cause a grafted cion on your peach or pear or apple tree to conform in shape or constitution to the stock on which it grows merely by giving it the same nourishment that the stock receives—for as explained above all the most important functions of plant life are carried on in the leaves. Thus we may have an explanation of the fact that the graft governs the root almost absolutely as to variety or individuality, while the roots are purveyors for the foliage.

Sap-Hybridism

Nevertheless, I have had at least one experience in the course of years of practice in grafting that seems to demonstrate the possibility of the transfer from cion to stock of qualities that transform in a very tangible degree the essential characteristics of the plant.

I refer to a case in which the twig of a purple-leaved plum (*Prunus Pisardi*) that I received from France was grafted on an old Kelsey plum tree which stood just at the corner of the vine-covered cottage on my old place in Santa Rosa.

The graft was made in the season of 1893. I was exceedingly anxious to cross this new and interesting importation with some other plums, so watched it very carefully. But much to my disappointment, no blossom or signs of blossom appeared during the year. So there was no possibility of making such an experiment as I desired.

Imagine then my astonishment when from a quantity of seeds gathered from the Kelsey tree there grew next season, among other seedlings, one with deep purple leaves. This strange seedling proved to be a thoroughly well-balanced cross between the original purple-leaved imported

graft and the Kelsey, a variety of *Prunus triflora,* upon which the graft was growing.

There was a most perfect balance in foliage, fruit, and growth so far as I could judge. One of the new seedlings was light purple in foliage throughout the season. Its fruit was small, nearly globular, and purple in color even when only half grown, while the Kelsey is an extremely large, heart-shaped, greenish plum.

Absolutely everything about the appearance of this strange seedling seemed to suggest that it was a cross between the purple-leaved imported plum and the Kelsey. There was no other purple-leaved plum within thousands of miles. The cion had not bloomed, and so crossing could not by any possibility have occurred in the ordinary way.

There is no escape from the conclusion that this was a case of so-called sap-hybridism, the very existence of which has been doubted.

The purple-leaved cion had without doubt influenced its host in such a way as to produce what was a hybrid progeny.

The new purple-leaved seedling was grafted upon an old tree, and in due course I produced several thousand second and third generation offspring from the original seedling. The fruit is of a characteristic red color, and in flavor

closely resembles the fruit that the original purple-leaved cion subsequently bore. In size the fruit is intermediate between that of the purple-leaved cion and that of the Kelsey.

The descendants of this hybrid stock vary in the second and succeeding generations, just as they might be expected to do had they grown from a hybrid seed produced by pollination; thus affording additional evidence that we have to do with an actual case of sap-hybridism.

Grafting to Save Space and Time

This record is made at length because of its extreme unusualness.

Never in the entire course of my wide experience have I seen another case in which I could trace such definite influence between the grafted cion and its foster parent. And so we may take it as a safe general rule that a cion, however grafted, will retain the characteristics of its parent stock, and that the tree on which it grows will be fundamentally uninfluenced, so far as the character of its fruit is concerned, by the graft.

It is not at all with the expectation of influencing the fruit product of either cion or stock that the familiar process of grafting is resorted to. The chief object of grafting, as practiced

in my own orchard, is to economize space and save time. As to the former point, it will be obvious that where hundreds of grafts from different seedlings are grafted on branches of a single tree, we are enabled to watch developments among these hundred of specimens, and by uprooting the original seedlings to utilize the ground they occupy for other purposes.

As to time saving, I have discovered that by grafting cions near the tip of the branches of the foster parent, instead of near its trunk, the cion comes much earlier to maturity, and bears fruit in the second season instead of having to wait until the third or fourth, or many years, as otherwise would be required.

So it is that on a single tree in my orchard half a thousand different seedlings may be tested simultaneously; and by the practice of selection of early-bearing varieties during the past forty years, I have produced a type of seedlings which almost invariably bear the second year from grafting. Indeed, so universal is this, that not one unfruited cion in a thousand will be saved for the third year unless it possesses some remarkable quality of growth, or shows peculiarly prominent and rounded buds, associated with the thick, broad foliage that betokens unusual possibilities of future fruit bearing.

The reader who has followed the accounts of the long series of experiments necessary to develop, say, an early-bearing cherry or a stoneless plum will appreciate in some measure the value of a system of grafting which shortens by two to ten years the interval between successive generations.

It will be readily comprehensible that by the use of these grafting methods I have been able to attain success in development of new varieties of fruits in less than half the term of years that would otherwise have been required.

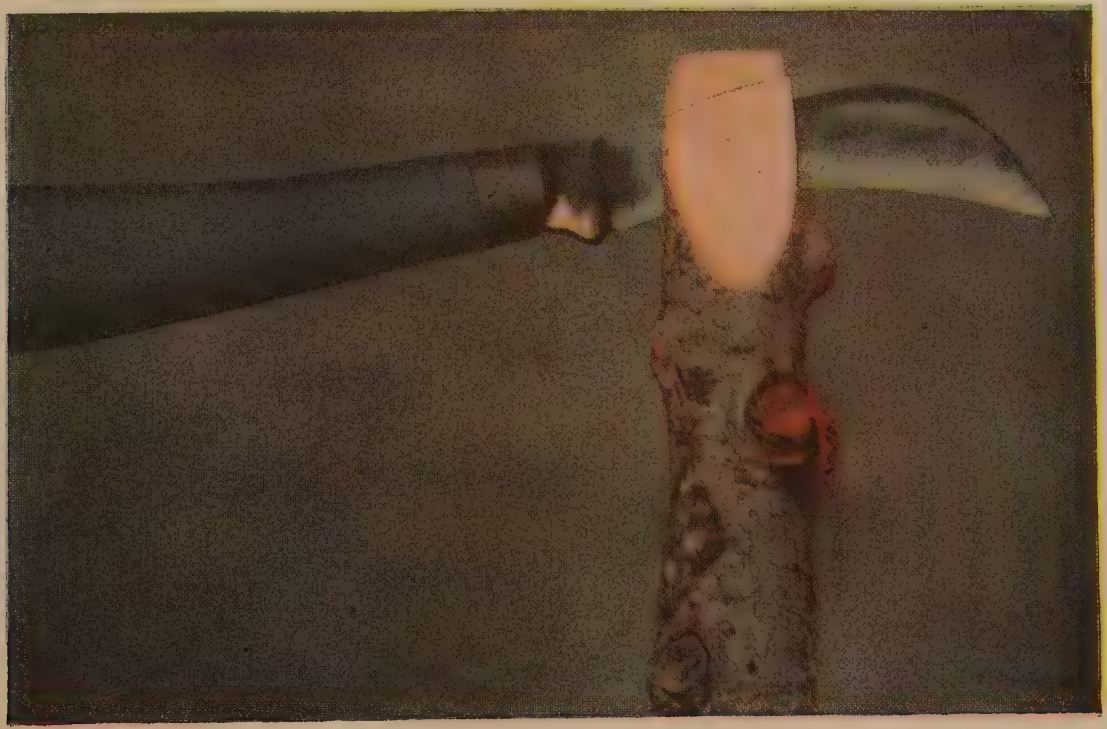
General Principles of Grafting

The single principle that underlies all successful grafting, is that the layer of tissue called the cambium layer, lying just beneath the bark of the twig, shall be brought in intimate contact with the corresponding layer of tissue of the stock on which it is grafted. The life-giving sap flows through this thin layer of tissue only. As to the central woody tissues—the so-called heart of the twig—there will be no union between stock and cion in any case.

But this is of no consequence since the new growth of wood soon covers the trivial wound with which the cambium layer will make ready union under favorable circumstances; and the

CUTTING STOCK FOR WHIP GRAFT

The stock cut on one side is split with the knife to receive a cion. The picture shows the exact method of procedure. It will be seen that this is a modification of the cleft graft. The whip graft is used for small branches, usually not as large as the one here shown.



growth will continue outward, year by year, until ultimately the cion and stock are so firmly joined that they constitute a branch as strong as the ungrafted branches of the tree.

But unless the living tissues of the cambium layer are accurately joined, no union can take place, and the graft will be a failure.

If this essential principle is borne in mind, the process of grafting becomes a comparatively simple one, and one that may be carried out successfully by amateurs with very little preliminary practice.

A few specific hints as to the details of the method may, however, be of service. So I shall give a brief account of the methods employed in my orchards, where the process of grafting is carried out thousands of times each year.

Grafting may be divided under three headings: (1) Grafting proper, in which a cion or small shoot is inserted into or upon the stock; (2) Inarching, in which the cion is left attached to its parent stock until union with the new stock is completed; (3) Budding, which consists of the insertion of a single bud upon the cambium layer of the stock. There is no fundamental difference between the three processes; they are merely different methods of accomplishing the same purpose.

Grafting may be more or less successfully carried on at any time of the year. But during the spring and early summer months the vital cambium zone is usually at the maximum of activity, forming wood tissue from its inner surface and bark from its outer surface. At this time of maximum growth, wounds are rapidly healed, and union between a cion and stock is most rapidly secured. Nurserymen and fruit growers take advantage of this fact.

The most gratifying results almost always follow spring grafting or summer budding. It is necessary, however, that there should be activity enough in the sap movement to form the cellular connection between the stock and the bud before the latter perishes from drying out; sap flow is also necessary to allow the bark to be lifted readily from the cambium for the insertion of buds.

The best success usually follows the grafting of mature, or nearly mature, buds in the case of trees and shrubs; though young tender buds often thrive nearly as well.

The More Common Methods

The best and quickest way to graft young seedlings is by "side" grafting. This graft is made by taking a piece of the new wood from

the tree to be multiplied, about 2½ inches long with well formed buds on it. Slice off both sides of the lower end of the graft in the form of a sloping wedge, the cut on each side being not much over one inch long. Both sides should be alike, but one of the *edges* should be thicker than the other.

The tree to be grafted is bent to one side with the left hand. With the right hand a sloping gash is made downward on one side of the tree just above the ground, and the graft, described above, is pushed down into this cut as far as it will go. The cambium layers of the cion and seedling meet at some point, and a union with the tree is formed. After the cion has been placed, the tree is allowed to spring back to its upright position, and is at once cut off with a pair of pruning shears, about two inches above the graft.

Warm wax is sometimes applied with a small paint brush over the wound to keep out the water, germs, and dry air, though waxing is often omitted with good success if the graft is well covered with earth leaving a single bud above the surface.

In grafting cions on the branches of trees, as in transforming large trees or whole orchards, the so-called "cleft" graft is usually employed.

A SIDE GRAFT IN POSITION

The side graft is made by bending a branch or small tree and making an oblique incision with a knife. The cion is cut in wedge shape as for a cleft graft, and it is, of course, inserted in such a way as to bring the cambium layers in contact. The process is completed by waxing, as with the other forms of grafting.

In preparing for this, the branch of the stock tree is sawed off at a convenient place, the exact position being determined by the character of the experiment. If we are seeking to make a permanent tree, the graft is implanted upon the limb not more than a foot or two from the trunk. But where it is intended merely to test the cion as to its fruiting possibilities, time being an object, it is placed far out among the smaller branches by what is called the "tongue," or "whip," graft.

In sawing limbs over an inch thick to serve as stocks, care must be exercised that the limb does not split. In order to avoid this, saw part way through from the bottom, and finish it by sawing from the top. Most persons who graft do not trim the stock after it has been cut, but I have found that the cambium layers join much more readily if the top of the stock is trimmed carefully with a knife so that it is smooth all around the edges. Clean incisions heal best with vegetable as with animal tissues.

In making the "cleft" graft, the stock is split with a grafting tool. The wedge-shaped portion of this tool is for the purpose of holding the cleft open until the cions have been inserted. The cions are cut and connected with the bark usually one on each side of the cleft. When the tool is

removed, the sides of the stock hold the cions tightly so that it is seldom necessary to tie a string or piece of cloth around the graft. It is usually best to put on a piece of cloth, however, after waxing. This insures more uniform results.

Grafting wax, a formula for which will be given presently, is usually applied several inches below the crack which was made for the cleft in which to insert the cions.

In some cases, however, the stock will later crack below the point where the grafting wax was applied, and when this occurs there is danger of the graft dying. For this reason it is wise to examine the grafts and where any open crack is found, additional wax should be applied.

There are various modifications of the cleft graft. One is used for the walnut and fig which it is almost impossible to graft by the common cleft graft.

Modifications are made as follows: Instead of splitting the cleft, triangular grooves are made with a fine-toothed saw on several sides of the stock. The edges of these splits are pared smooth with a sharp knife and the cions which are usually large, after being carefully fitted, are driven into these slits with a small mallet. Strong cords are then bound around the stock to help keep the grafts in place until they have

united with the stock, when they may be cut to give room for further growth.

All cut surfaces should be carefully waxed as in ordinary cleft grafting.

It is well to tie ordinary paper sacks over the grafts, covering the stock as far down as it has been cut. These are allowed to remain until the buds have made a good start when they may be torn open and finally removed.

In making all grafts, care must be exercised in getting the cuts on cions and stocks smooth, so that the parts may fit closely together. In the cutting of each side, a single bold clear cut is better than whittling and trimming.

The "tongue" or "whip" graft is used in making bench (i. e., indoor) grafts and sometimes in "top grafting" trees. Top grafting consists in placing grafts on the various branches of a tree in order to change it over to the new variety. The tongue graft differs from the cleft graft in that there is a cleft and wedge on both cion and stock. These interlock when closely pressed together. This mode of grafting is seldom used except on branches less than one-half inch in diameter. It is very difficult to make the proper cut on branches larger than this. In top grafting large trees, it is often well to graft only on the strongest branches one season, and

on the smaller branches the next. In general practice, however, a whole tree is usually grafted over at the same time.

"Bark" Grafting and "Inarching"

In grafting chestnuts a modified method called "bark" grafting is best. The cion is trimmed very thin and quite a space is allowed for the cambium layer to come into contact with the cambium layer of the stock. A T-shaped slit is made in the bark of the stock, cutting through to the cambium layer. The flaps about the vertical slit are turned back, the cion inserted, and the lips of the bark closed over it and bound firmly with a piece of cloth or strong twine to give good support. Grafting wax is applied freely.

Such grafts are usually made on a fairly large stock where it would be impracticable to split the stock. As a rule four cions are inserted on one stock. If they should all live, two may be removed, as the grafts do best when not too much crowded.

"Inarching," as already stated, differs from ordinary grafting in that the cion is left upon its original roots until the union is made.

The plant from which the cion is to be taken is planted close to the plant that is to serve as

the stock. The two are brought together and the bark sliced from a branch of each so that the cambium layers come together. This connection is bound and waxed. After union has taken place, the cion is cut off below the union and the stock is cut off above it, thus leaving the cion on a new stock.

This process is only exceptionally used, as it requires too much time and expense, and with most plants is usually no more successful than the simpler methods of grafting, yet with certain plants it is the only successful method.

Grafting Wax

Mention has been made of grafting wax, as being very generally used to protect cion and stock during the progress of healing and union of tissue. After testing many formulas, I selected the following, and no other has been used for many years.

Eight pounds of common resin and one pound of beeswax or paraffin (either will do if no acid or alkali is present, though beeswax is generally preferred) are mixed with one and a half pounds of *raw* linseed oil. Boiled oils often contain chemicals injurious to plant life. If the wax is to be used in cold weather, it is better to use only seven and a half pounds of resin and a half

CROWN OR BARK GRAFT

For this graft the stock is sawed off as if for a cleft graft, but the incision is made, as shown opposite, to include the bark only, exposing the cambium layer. The cion, cut only on one side, is inserted, and a waxed bandage is applied. The cion here is not at first held quite so securely as in case of a cleft graft, but, on the other hand, the stock is not split, which is an advantage. This method can only be used late when the bark slips.

pound of beeswax in the mixture, thus giving slightly thinner consistency.

The ingredients are slowly heated together until the resin and wax are melted and all thoroughly combined. This composition when partly cooled is poured into pressed tin pans, to make cakes of convenient size for handling. The mixture sticks to the tin with great persistence; but by turning the pan upside down and pouring boiling water over it for a few seconds the wax can be shaken from the pan.

These cakes are broken into pieces of convenient size, and in use the wax is kept warm in any convenient dish or pan having a short strong handle. The wax may be heated over a small coal oil stove, and when applied to the grafts should be much warmer than can be borne by the hand, but not hot enough to scald the plant tissues. If heated in a double heater, the outside one containing water, the danger of overheating is lessened.

If applied with care with a small paint brush, first around the thick bark of the stock, and later, as the wax on the brush cools, on and about the cuts and open joints, no harm will result. The plan of brushing the hot wax about the graft, instead of applying it by the fingers in the tedious old-fashioned way, saves nine-tenths of

one's time, and does far better work than could ever be done by the old method.

If the wax should prove to be too soft and sticky, as is sometimes the case in very warm weather, melt it over again with more resin added. If too brittle, add a little more linseed oil so as to bring it to the right consistency to spread well, and at the same time "set" well on cooling. It gives the most satisfactory results when about the consistency of ordinary chewing gum.

Properly applied, the wax serves as a valuable protective and germ-excluding dressing, comparable in its function to the aseptic dressing applied by the surgeon to wounds or after operations.

Multiplication by Budding

There is one form of grafting which differs so radically from other methods that it is often thought of and spoken of as if it were a totally different method. This is "budding"; that is to say, the process of transplanting a single bud from one tree to another. This is really only a special case of grafting; it differs from other methods only in that in ordinary grafting the cion usually has several buds instead of a single one. As a practical procedure, therefore, budding has the advantage of supplying several

grafts from what by the other method would be only a single cion. Therefore budding is generally used for the production of nursery stock on a large scale, or for the introduction of rare varieties, grafting material for which is costly or difficult to secure.

The method of budding is closely similar to the method of "bark" grafting, already described, except as to season—which, for budding, is June, July, and August, while the trees are in full leaf. A piece of bark about an inch and a half long, with a well-ripened bud, is sliced from a twig of the variety desired, the incision being just deep enough to include the cambium layer and often a minute portion of wood.

The bark of the stock is slit horizontally and vertically to form a T; the size of the slits being determined by the size of the bud to be inserted. The upper corners of the vertical slit are gently lifted with a knife and turned back to reveal the cambium layer. The bud is pushed under the bark; the flaps of which are brought over it and securely tied. Waxing is not necessary.

In ten to fourteen days the bud becomes united to the seedling and the binding cord may be loosened or removed.

The bud remains dormant until the next spring. When the leaves begin to start, the tops

CUTTING THE BARK TO RECEIVE A BUD

A T-shaped incision is made in the bark of the stock on which the bud is to be grafted, the edges about the vertical slit are turned back, exposing the cambium layer. The slice of bark with the bud is then slid into this pocket and the bark of the stock is folded about it and secured with a string.

of the seedlings are cut down to within two or three inches of the bud, all buds being at the same time removed except the one inserted the season before. Thus the vigor of the tree is thrown into the new bud, and by fall we usually have well branched trees from three to six feet high, according to soil and climate, from the single bud which was placed in the seedling the preceding summer.

Sometimes instead of allowing the buds to remain dormant over winter they are placed on the young seedling trees earlier in the season. Fully ripened buds for such transplantation may often be obtained in June or early in July. After the bud is inserted, the tops of the young trees are at once broken over at about half their height, leaving only a piece of bark and a part of the wood to continue circulation. If the whole top is removed the result is failure.

When the weather is moist or where irrigation is practiced, the buds will often start out even before they are fully united with the stock, though there is a great difference in this respect. Some varieties of hybrid Japan plums and even the common French prune often make three to six feet of growth the same season.

These are called June buds by nurserymen. When well grown they are excellent trees, as

they can be transplanted, leaving the whole root system complete, whereas with trees two years old, some of the roots have to be destroyed in transplanting. Another great advantage in the June bud or yearling over the larger two year old trees, especially in California, is that the tops can be cut down low to form heads of any uniform height desired because all the side buds are young and fresh.

Hints as to Heading and Culture

With most fruit and ornamental trees, the stocks are secured by planting seed. These are planted during the winter in California, and during the fall or early spring in the colder Eastern States.

In general practice, seedlings of pears, cherries, apples, etc., of one year's growth are purchased by nurserymen. These are purchased from growers who make a specialty of producing seedling stocks in large quantities. Most of these were imported from France, though American seedlings are being more and more used. These young seedlings are lined out in rows for field culture about four feet apart, being planted from six to twelve inches apart in the rows.

During the summer following, usually in July or August for cherries, plums, and peaches, and

in September for apples and pears, budding may be done to best advantage.

If there is a marked difference in rate of growth of cion and stock, or if for any reason the two do not blend to advantage, an ugly swelling often results at the point of union; hence the experienced grower avoids making such combinations.

These plant affinities cannot be foretold; they can be determined only by experiment. As already pointed out, the success, vitality, and growth of a graft will very largely depend upon the affinity between cion and stock; occasionally species from different genera may be satisfactorily grafted.

Some of the pears often thrive even better for a time and produce superior fruit when transferred to a hawthorn or apple stock. Almond cions thrive well on peach or plum seedlings. Apricot cions grow and thrive well on seedling plum or peach stocks.

Cherry cions do well on seedling stocks of the wild Mazzard cherry of Europe. The Mahaleb cherry is sometimes used when it is desired to have dwarf-growing trees. The peach generally thrives on its own roots only. Apples thrive best on their own roots or on various wild crab apple roots.

THE BUD GRAFT COMPLETED

This shows the completion of the process of bud grafting, preparation for which is shown on a former page. It is not necessary to use grafting wax, as the string will hold the bark securely in position until union has taken place —usually from ten to fifteen days. The string should then be removed, that it may not constrict the tree.

Pear cions do well on seedlings of wild or inferior varieties of pears. Most of the seedlings grown in this country are grown from seeds secured from Europe. Quince stocks are sometimes used for certain pears, more especially for dwarfing and bringing into early bearing.

Seedlings of the hardiest and most vigorous growing varieties of plums, either European or American, may be used for plum stocks. The myrobalan plum from France is a favorite. The peach is also used for some varieties.

If it is desired to test the qualities of hundreds or thousands of seedling fruits, a knowledge of grafting is of the utmost importance, as several hundred varieties may be readily tested on a single tree.

On my Gold Ridge Farm there are *single acres* on which ripen several thousand distinct varieties of hybrid seedling plums that could not properly be tested one each on a separate tree on less than about *seven hundred acres* of land. Besides, a seedling grafted into a bearing tree usually produces fruit in two or three years, but if the same seedling were planted as usual and allowed to fruit, it might require five, ten, or fifteen years. There is still another advantage in grafting many seedlings on a single tree; a better opportunity is afforded for *comparative* tests; if

scattered over a large orchard, some trees might be in better condition, or have better roots or better soil than others, and thus no accurate comparative test could be made.

In grafting for the purpose of testing seedlings, the weaker-growing seedlings are placed on the strongest-growing branches of the tree, the stronger growers being placed toward the outside and lower down on the tree and on the smaller branches.

When so many varieties are grafted on a single tree, some may be extremely vigorous growers, others only moderately so, and still others will be weak, slow growers. In the winter pruning we always take pains to give the weaker growers plenty of space to develop, while the stronger growers are severely pruned.

It is no small matter to prune properly a tree on which several hundred varieties are being tested. An ordinary pruner might ruin the tree in a few minutes, by leaving the most worthless varieties almost covering the tree, while smaller, slower-growing varieties of great value might be so crowded that they would either die or become stunted and bear no fruit. This later aspect of the process of grafting, then, is one that imperatively demands the attention of the plant developer himself, or of his most skillful assistants.

LETTING THE BEES DO THEIR WORK

Nature Helps Us

OUT in the desert regions of the southwestern United States there grows a very remarkable plant called the yucca, or Spanish bayonet. Doubtless you have noticed it from the car window, or you may have seen it growing in a garden. Its bristling array of bayonetlike leaves gives it a very individual appearance, and the cluster of creamy white flowers that it puts forth on its tall central stalk gives it added distinction.

But even if you are familiar with the appearance of the plant, you perhaps have never heard the wonderful story of its alliance with a particular species of insect, upon which alliance the lives of both plant and insect absolutely depend.

The story is one of the most curious ones in the entire range of plant and animal life. Cases of so-called "symbiosis," in which an insect and a plant are mutually modified for mutual aid, are

common enough in nature. But so extreme a case as that of the yucca and the insect that is its inseparable associate is seldom duplicated.

The insect in question is a little yellowish white moth, so unfamiliar that it probably has no colloquial name, but known to the entomologist as the *Pronuba yuccasella.* If you were to watch closely you might see these moths visiting the flowers of the yucca in the twilight. You would require exceptional opportunities for observation if you were to discover precisely what takes place during this visit. But entomologists have kept watch to good purpose, and the terms of the extraordinary coalition between the yucca and the pronuba moth are now an open secret.

It appears that the female moth that visits the yucca blossoms has developed a long ovipositor with which she can pierce the tissues of the ovary of the plant and so lay her eggs within it. Her prime object in visiting the yucca flower is thus to deposit her eggs. In due course the eggs hatch and the growing seeds of the yucca will furnish them a supply of food. So there is nothing very remarkable about this part of the procedure.

The surprise comes when we learn of certain maneuvers preliminary to the deposit of the eggs. If you could watch the little moth on her visit to

the first flower, you would see her begin at once industriously to gather the adhesive pollen grains with the aid of a curious pair of tentacles growing about her mouth; tentacles unlike those of any other moth.

As the pollen grains are gathered they are rolled into a small pellet, and when this is of a satisfactory size, the moth leaves the flower and flies to another.

But here, instead of continuing her task of pollen-gathering, the insect makes her way to the center of the flower and, piercing the basis of the pistil with her ovipositor, lays her eggs among the embryo seeds of the ovary. Then she crawls carefully up the style and, poising at the tip, pushes the little ball of pollen down into the cavity of the stigma.

By this apparently preconceived and carefully perfected plan, then, the little moth has obviously done precisely the thing necessary to insure fertilization of the flower in which her eggs are deposited, with pollen from another flower.

No plant experimenter, whatever his skill, could have done the thing better.

Cross-fertilization is assured; the ovules among which the eggs of the moth were deposited are sure to develop, giving an abundant supply of food for the larvæ when in due course they are

hatched. The little grubs will grow and thrive, and presently will eat their way out of the ovary and fall to the ground, where they will bury themselves for a season; coming forth as adult moths in the succeeding summer, just at the time when the yucca is flowering.

Service for Service

At first glance it is not obvious how the yucca profits by this curious arrangement.

But observation shows that the progeny of the moth seldom or never consume all the yucca seeds that are so conveniently stored about them. After they have eaten their fill and have sought a new shelter, enough yucca seeds remain to insure perpetuation of the species. The progeny of the moth have indeed taken toll of part of the crop of yucca seeds in recompense for the services performed by their mother.

But, on the other hand, had the moth not paid its visit, the flower would by no chance have been fertilized at all.

Here, then, is a case in which there is absolute mutual dependence between a particular species of insect and a particular species of plant. In the desert regions it inhabits the moth could find no other place to deposit her eggs where food would be assured her offspring; and in the burn-

ing desert air the stigma of the yucca, if not placed deep within the tissues, could hardly endure exposure and still perform its function. The arrangement between stamens and pistil of the yucca is such that no other insect is likely to pollenize it, even were there other insects at hand.

Altogether this is one of the most curious and thought-provoking instances in all nature of mutual dependence between an animate creature and a plant.

One can scarcely leave the yucca and its strange visitor without inquiring how so extraordinary a coalition could have been brought about. Unfortunately no very precise answer can be supplied. We can only assume that the complex and intricate relationship now manifested is the final result of a long series of slight adaptations through which insect and plant were mutually specialized in such a way as to conform to each other's needs.

It is impossible to conceive that any sudden mutation of form on the part of the plant or of habit on the part of the insect could have led to so complicated an alliance.

The change must have been very slow and gradual. First, we may suppose a condition in which the ancestors of the yucca were sometimes

visited by the ancestors of the moth, but were not dependent on them for any very complicated method of pollination. Then successive ages in which the moth gradually developed its special pair of pollen-gathering jaws, while the plant correspondingly shortened its pistil and became more and more dependent upon the peculiar process of fertilization to which the moth was becoming adapted.

To anyone who has not thought long and carefully, with the examination of many examples, along the lines of the evolution of organic forms through natural selection, as explained by Darwin, all this will probably seem rather vague and unsatisfactory. And, indeed, it must be admitted that among all the extraordinary cases of adaptation through which insects and plants have come to be mutually helpful, this is at least as difficult to understand as any other.

The seeming intelligence of the act of gathering and depositing the ball of pollen is emphasized by the fact that this pollen is never of *direct* use to the progeny of the moth, yet is vitally important to them *indirectly* because it fertilizes the seed embryos of the plant that are to serve them as food. At first glance, then, one can scarcely escape the thought that the moth must have had some such comprehension of the plant's needs as

that which leads the human plant experimenter to cross-pollenize his flowers.

One might even be excused a momentary half-conviction in a certain direction that the insect must be endowed with intelligence almost of the human order.

Plant Intelligence

Such a thought is dispelled, however, when we reflect on the seeming intelligence of plants themselves and the apparently well-reasoned schemes by which certain flowers insure the taking of effective toll of the insects attracted by the nectar.

Even in the case of the yucca, it will be observed that the plant was not quite a passive partner in the arrangement through which the perpetuation of its kind was assured. The pistil of the flower had gradually been depressed below the pollen-bearing anthers, in full confidence that the moth would carry out its share of the mutual compact. And when we reflect that this conformation of stamens and pistil was doubtless modified from an earlier arrangement less advantageous to the plant, we are confronted with evidence of a seemingly intelligent capacity to adapt its structure to its needs on the part of the plant that to some extent matches the apparent intelligence of the insect.

READY FOR SHIPMENT

These are bundles of young trees, wrapped so as to insure entire protection, being shipped to various localities for testing under different conditions, notably with regard to hardiness. Extensive tests are often made in widely separated regions before a new variety is introduced.

Similar evidence of apparent design on the part of flowers in the arrangement for guarding against self-pollination meets us everywhere on every side.

Consider, for example, the way in which the lilies project the receptive stigmas far beyond the stamens; or the way in which the amaryllis, the carnation, the balloon flower, the geranium, and numerous others effect the same purpose by careful provision that the stamens and pistils of any given flower shall not come to maturity at the same time.

Then there are plants like the sage, the stamens of which seem to lie in wait for the visitor; being observed to bend quickly over, under stimulus of contact, and rub their pollen on either side of the insect's back. Again there is the milkweed (*Asclepias syriaca*), which stores its pollen in tiers of handbags connected with a strap that entangles the feet of the bees—and which, in its overeagerness to make sure of the transfer of its precious wares, sometimes defeats its own purpose by so overloading the insect that it cannot fly away.

There are some water plants, too, that adopt methods to secure cross-fertilization that are ingenious and wonderful almost beyond belief.

Thus the little water plant called *Villarsia nymphoides* sends out its flowers from its submerged haunts as little detached balloons that float to the surface of the water and then burst open to offer their pollen to the insect messengers.

And the eel grass (*Vallisneria spiralis*), by an even more wonderful arrangement, projects its pistillate flower up to the surface of the water on a long spiral stem grown solely for that purpose; while its staminate flower strains at the short stalk on which it is tethered until it breaks away and rises detached to the surface. The pistillate flower, once pollen has been brought to it by its detached floating mate, which drifts off to perish, is drawn again beneath the water by the recoiling stem, never to reappear.

In the preevolutionary days, such instances as these were cited as giving incontrovertible evidence of design in nature.

But no one nowadays regards them in that light, if we use the word in the old teleological sense. Since Darwin taught us the way, we are able to explain these marvelous adaptations; but as evidences of the operation of the great principle of natural selection they are no less wonderful.

And most remarkable of all, as viewed from the present standpoint, are the orchids, the ex-

traordinary pollenizing devices of which were first made generally known through the studies of Darwin. A familiar illustration of the methods adopted by this curious tribe is furnished by the species known as *Orchis mascula*, which bears its pollen in small bundles at the end of a slender stalk, at the other end of which is a disc covered with a sticky secretion. An insect cannot secure nectar from the flower without carrying away at least one of these pollen stalks.

But the most remarkable part of the operation is that, so soon as the insect withdraws from the flower, the pollen stalk, attached hornlike to its head, bends over and curls itself into precisely the position that will inevitably cause it to strike the pistil of the next orchid that the insect visits.

Another species of orchid, known as *Orchis pyramidalis*, grows two pollen bundles held together by a sort of collar, with which it decorates its insect visitor, clasping it, for example, about the proboscis of a butterfly. Here as in the other case the pollen carriers adjust themselves in precisely the right position for the deposit of their important burden; and in this case the arrangement is such that a portion of the fructifying powder is deposited on each of the two pistils with which this species is equipped.

The Senses of Insects

It is needless to multiply instances of the wonderful adaptations of form through which the various species of plants have made sure that the insects for which nectar is provided shall carry out their part of the bargain.

Some flowers have long tubes which only the coiled proboscis of a moth or the slender bill of a humming bird can fathom. These are sure to provide pollen carriers of a bulky character which only humming birds or large insects like the moth could transport. Mechanisms are even provided to exclude from the nectar chamber bees and other small insects that could be of no service to the flower.

But such cases, while in the aggregate numerous, are on the whole exceptional. In general the plants with which the horticulturist deals, and particularly the plants of the temperate zone, have contented themselves with a much more simple arrangement, whereby the pollen bearers are so arranged that any small insect that visits the flower is almost sure to go away laden with pollen.

But, in particular, provision has been made by the vast majority of flowers of the orchard and garden to attract a single species of insect, the bee.

This familiar insect, the one member of its vast tribe that is very directly helpful to man as a producer of food, is the indispensable coadjutor of the most important varieties of cultivated plants. Bees of one species or another are the universal distributors of pollen in orchard and garden. The beautiful flowers that the apple and plum and cherry put forth, and the perfumes they exhale, are primarily designed as advertisements for the bee and the bee alone.

Whoever realizes this truth will not be likely to doubt that the bee, in common with other insects, has good olfactory organs and an eye for the discernment of color. Yet there have been entomologists, even in recent times, who have questioned whether insects really have the sense of smell, and others who have challenged their color sense.

As to the latter point, whoever has taken the trouble to observe the maneuverings of an individual bee in the flower garden, and has seen it pass from one red flower to another, quite often confining its visits exclusively to blossoms of one hue, will have gained sufficient evidence that the bee is by no means color blind.

As to the sense of smell, if further evidence than that supplied by everyday observation of the visits of insects to perfumed flowers were

required, it is furnished by an interesting and remarkable experiment made by Professor Jacques Loeb, formerly of California University, now of the Rockefeller Institute in New York. Professor Loeb placed a female butterfly in a cigar box. Closing the box he suspended it in mid-air between the ceiling and floor of a room, and opened the window.

"At first," says Professor Loeb, "no butterfly of this species was visible far or near. In less than an hour a male butterfly of the same species appeared on the street. When it reached the high window its flight was retarded and it came gradually toward the window. It flew into the room and went up to the cigar box upon which it perched. During the afternoon two other males of the same species came to the box."

A commentator observed that the experiment makes it unequivocally clear that insects possess an olfactory sense of almost inconceivable delicacy. But the question as to what is the real character of the stimulus that produces the sense of smell is one of the mysteries of science.

"A substance like musk," he says, "may give out a characteristic odor continuously for an indefinite period, while the substance itself appears to lose no weight. If particles of the odoriferous substance are really thrown off, these particles

must be almost infinitely tenuous. If, on the other hand, the stimulus is due to the giving out of waves or vibrations comparable to the waves of light or of sound, the nature and other characteristics of these manifestations of energy are absolutely unknown."

Another experimenter has shown that ants will follow a trail that has been made by other ants bearing honey or sugar. The inference seems obvious that the ants are following a very delicate trail by the sense of smell. But perhaps it is well, considering the unrevealed nature of the stimulus associated with odors, to adopt Professor Loeb's cautious phrasing and speak of the sense through which insects are guided to odoriferous objects as "chemical irritability."

The fact that a bee is able to travel in a straight line backward and forward between its distant hive and the flower bed or the apple tree from which it is harvesting, even though the distance be a matter of miles, suggests the possession of organs of sense of a far more delicate character than our olfactory nerves.

It is hardly probable that vision is an important aid in these long-distance flights; for Professor Loeb's experiments have led him to infer that the dioptric apparatus of insects is very inferior to the human eye. Moreover the flowers

A HYBRID EVERGREEN

This is a cross between the cypress and the juniper. Our evergreen trees somewhat frequently hybridize in a state of nature. This is not strange, considering that the conifers send out their pollen in clouds to be scattered at random by the winds.

would scarcely find it necessary to put out expensive corollas and deck themselves in gaudy colors if their signals were meant for creatures having very acute vision.

In point of fact, the complex multiple eye of the insect, devoid of any such adaptive apparatus for focusing as the lens of the mammalian eye, does not suggest acuteness of vision, but rather a more or less vague appreciation of large masses of color.

The recent experiments of Dr. Charles A. Turner, of the St. Louis Academy of Science, have, indeed, demonstrated that bees can distinguish between color patterns as well as between different colors. But, although the tests of the naturalist Plateau, which seemed to show that insects are attracted solely by odor, are thus controverted, it doubtless remains true that the sense of smell—or some equivalent sense of a kind as yet unanalyzed—is the chief guide in bringing insects from a distance to the vicinity of flower bed or fruit tree.

Professor Loeb declares that the "chemical irritability" of the insect, as excited by odoriferous objects, is immeasurably superior to the sense of smell of human beings, and possibly even finer than that of the best bloodhound. Observation of the honey gatherer making his "bee line" from

hive to orchard and back again prepares us to accept this statement at its full valuation.

There must even arise a question as to whether the insect's equipment of "chemical irritability," or whatever it may be called, does not amount to the possession of a sixth sense.

Aiding the Bee

We have instanced over and over the vital importance of the process of cross-fertilization which the bee accomplishes for the flower.

It may be of interest to cite a few familiar illustrative instances of devices adopted by certain familiar flowers to make the services of the bee surer and more effective. Inasmuch as the bee has no conscious share in the plant's solicitude to effect cross-fertilization, it has been found expedient on the part of many flowers to adjust the arrangement of stamens and pistils in such a way that the visiting insect shall surely receive a modicum of pollen, yet cannot rub this pollen against the stigma of the same flower.

Some illustrations of what might be called extreme measures to prevent such inadvertent self-fertilization were given earlier in the present chapter. Let us note a few additional instances, with reference in particular to flowers that are largely pollinated by the bee.

A simple and effective method of guarding against self-pollination we have seen illustrated in the common geranium (*Pelargonium*).

When the geranium flower first opens, a little cluster of anthers may be seen on the tip of the erect filament in the center of the bright, showy flower. At this stage the undeveloped stigma lies closely folded up and wholly unreceptive among the stamens. But soon after the pollen has been shed or gathered, the anthers drop off; then the stigma spreads out its five receptive lobes from the tips of the connecting filaments, and is ready to receive pollen from another flower.

In the snapdragon (*Antirrhinum*), and in many other related plants, the anthers lie along the roof of the corolla tube, where they are brushed by insects that pass down the tube in search of nectar. The stigma holds a similar position, but is farther out toward the mouth of the tube. The stigma is a very interesting structure; it is composed of two flattened lips, which respond to the slightest touch.

When a bee, after visits to other flowers, enters the tube, the hairlike appendages on its back brush against the lower lip of the stigma, and the irritation causes the lips to close quickly and tightly together, coming thus in contact with and scraping the pollen-dusted back of the bee.

Whether or not the receptive lips have secured any pollen, they remain closed for four or five minutes, so there is no danger that they will encounter the bee as it leaves the flower laden with a fresh supply of pollen from the companion anthers. But a few minutes later the stigma lobes open again, like a trap set for the next visitor.

Human ingenuity could not well devise a mechanism better adapted than this to secure cross-pollination and insure against the possibility of self-fertilization.

The foxglove *(Digitalis)* also has stamens and pistils lying along the roof of the corolla tube. Its device to prevent self-fertilization is the less ingenious but equally effective one of ripening the stigma only after the pollen has been discharged—an expedient which, as we have seen, is very commonly resorted to by other species of plants, including the lilies.

The Spanish broom *(Spartium junceum)* is a typical butterflylike flower, that, in common with others of the same family, has developed a peculiar mechanism to bring about cross-pollination. The two lower petals are joined together into a keel-shaped structure that connects the stamens and pistils. The other three petals are more enlarged, and are spread to

make a more effective advertisement, challenging the attention of insects. The visiting bee naturally alights upon the projecting keel. The weight of its body presses this downward and the stamens and pistils, by a springlike action, are thrust out against the body of the insect, scattering the pollen freely.

Thus the stigma may become covered with pollen that the bee has received from some other flower while the anthers supply a new coat of pollen for future distribution.

Still a different arrangement is that of the common iris. Here the anthers lie in a fold of the large petallike branches of the style. The stigmatic surface is confined to a little crescent-shaped patch near the tip of the style branches, and is protected by a thin, sacklike shield. The structure of the flower is such that an insect as it passes down the petals on its way to the nectary, brushes against the anthers and dusts off the pollen. As the insect passes out, the stigma shield protects the stigmatic surface completely.

But as the insect visits another flower, its pollen-covered back comes in direct contact with the edge of the stigmatic shield and the pollen is scraped off against the receptive surface.

These, then, are familiar illustrations of the really wonderful adaptations through which it comes to pass that the bees carry out their part of the ancestral compact that insures the plant such interchange of pollen as is essential to racial progress. Perhaps the most alluring feature of the entire coalition is that the bee performs its all-important function unwittingly in the course of the quest of sweets that appeal to its appetite. There is no compulsion in the matter; the plant depends upon the more powerful influence of persuasion.

And to add to the satisfactoriness of the entire arrangement, from a human standpoint, it must be recalled that the efforts of the industrious insect, which thus makes possible the work of the plant experimenter, result at the same time in storing the nectar gathered from the flowers to form one of the most delectable of foods.

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